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# Proceedings Of The Seventh Central Hardwood Conference



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Each conference registrant was eligible for 14 hours of Continuing Forestry Education (CFE), offered by the Society of American Foresters for attending this conference.

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# SEVENTH

# CENTRAL HARDWOOD FOREST CONFERENCE

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## PREFACE

The three primary objectives of the Central Hardwood Forest Conference are: (1) to provide identity to the central hardwood forest region as an entity, (2) to provide a communicative forum for scientists with a common interest in the central hardwoods, and (3) to coordinate regional research.

Although most Conferences have had a definite ecological and/or traditional forestry orientation, authors of the Foreword to the Sixth Proceedings (1987) suggested that the Seventh Conference (i.e., the present one) "devote a substantial part of the program to forest change due to the human element of the environment and to the needs of people for amenities of hardwood forests other than wood". These authors also suggested that if we, as forest managers, fail to include the human element in land management assessment we will most likely lose the confidence of the lay public. Partially in response to this type of concern, a panel discussion by policy level personnel in the Central Hardwood region was included on the first morning of this conference to discuss research management priorities.

The Seventh Central Hardwood Forest Conference was held on the campus of Southern Illinois University at Carbondale, Carbondale, IL, also the site for the first Central Hardwood Forest Conference. Attendance at these conferences has steadily increased, a measure of the quality of the research results, as well as acceptance of the need for this type of forum. We wish the hosts of the Eighth Conference at least equal success.


## ACKNOWLEDGMENTS

This conference was hosted by the staff of the Forestry Sciences Laboratory, North Central Forest Experiment Station, Carbondale, IL, and the Forestry Department and Division of Continuing Education, Southern Illinois University at Carbondale. The staffs of all three organizations contributed immeasurably to the success of the conference. The helpful cooperation of Martha K. Dillow, Michael W. Prouty, and Paul L. Roth were especially noteworthy. Also, the enthusiastic support and encouragement of Ronald L. Hay, Forestry Department of the University of Tennessee and Chair of the Program Committee of the Sixth CHFC is gratefully acknowledged. Similarly, session moderators are to be commended for keeping the conference on schedule.


## REVIEW PROCEDURES

Each manuscript published in these proceedings was critically peer-reviewed by at least two scientists with expertise in disciplines closely aligned to the manuscript subject matter. Reviews were returned to the senior author who revised the manuscript appropriately and resubmitted it in camera-ready form for publication by the North Central Forest Experiment Station, USDA Forest Service. Manuscript authors are responsible for the accuracy and style of their papers.

Pesticide and fertilizer treatments do not imply endorsement of chemical products or their method of application.

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# CENTRAL HARDWOODS: WHAT WE KNOW, WHERE DO WE GO[1]

F. Bryan Clark

Abstract.--An assessment of the status of management technology for central hardwood forests shows that practitioners have much information to prescribe for multiple-resource uses. However, guidelines for practical and extensive treatments are lacking for some forest types and sites. Additional research is needed in many areas including more long-term forest processes research.

## INTRODUCTION

The purpose of my presentation is to give you my perspectives on (1) where we stand on management techniques for central hardwoods and (2) what we need to do to fill gaps in our knowledge. My comments include views developed the past 2 years while helping prepare the publication, Central Hardwood Notes (In press), a review of the Proceedings of the Central Hardwood Forest Conference VI (1987), and, of course, my experience which covers 40 years as a research silviculturist and a research administrator from Missouri to Washington, D.C., with stops in between. One of those stops included participating in the First Central Hardwood Forest Conference. Finally, I will share some of my specific concerns about research priorities, solving practical problems and technology transfer.

## WHAT WE KNOW ABOUT MANAGEMENT

The Research and State and Private Forestry Branches of the USDA Forest Service gave me an opportunity to participate in a unique cooperative project called Central Hardwood Notes. The concept was to bring together the very scattered expertise on central hardwood management through a series of short, practical Notes. This first attempt includes 85 Notes and nearly 100 authors including practitioners and researchers. We likely overlooked some important subjects but oversights and changes can be easily accommodated through additions and revisions as new information becomes available. Since I reviewed all of the papers, I was exposed to the state-of-the art by a large number of specialists. You will hear more about this project in a later paper.

We have a great deal of technology that can be used to improve the productivity and usefulness of central hardwood forests. The Central Hardwood Notes should be very helpful to practitioners when dealing with a wide variety of resource problems and opportunities. Yet there are some technical areas where we do not have enough definitive information to do a better job, even after more than 50 years of research. But I don't think we have to apologize for our progress considering the efforts expended on the central forests and their inherent complex diversity and broad ecological gradients. We still need more specific informaion on probabilities of success, and we need specific guidelines for extensive, low cost, treatments. In many cases we do not have adequate data, experience or validation, but I am convinced that we could be more aggressive in interpreting and synthesizing for practical application. We are too conservative. That also applies to some of our scientific reporting. The following comments on the status of our practical knowledge relate only to those general areas covered by the Central Hardwood Notes.

## WHAT WE KNOW

We now have a good, general understanding of alternatives for silvicultural systems and how they are likely to meet the various needs of landowners. This information is based on many years of research and experience. The consequences of different kinds of harvest cuttings are generally understood, but our ability to shape future stands in some forest types is limited by lack of ecological knowledge, economic reality and failure to apply what we know. We know when it is safe to

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[1] Paper presented at the Seventh Central Hardwood Forest Conference, Carbondale, IL, March 5-8, 1989.

[2] Consultant and retired Associate Deputy Chief, Research, USDA Forest Service. Annandale, VA 22003.

cut, but we are not sure what to do when it is not. So we wait. And we still need more practical information on how and when to apply the shelterwood and selection systems and how to manage mixed hardwoods and the bottomland types.

Some of the important ecological and silvical characteristics of the different forms of natural hardwood regeneration are defined for most major species. Field foresters must have and understand this kind of basic technology to prescribe treatments. Guidelines to define adequate advance oak reproduction are especially helpful. Unfortunately, the guidelines are based on Missouri data, and they need to be validated and/or modified for other areas. We need similar regeneration guidelines for other species. After many years of research, theoretical prescriptions to establish strong advance oak reproduction remains unproven.

Prescriptions for planting pine and hardwoods have improved a great deal in the past 30 years. The importance of planting site evaluation, planting methods, stock care, stock quality, and weed control are well known by research and are all important to success. Unfortunately, when it comes to practice we do not do as well as we should in applying what we know. Survival rates are too low and too many off-site plantings fail. We have learned a lot about planting black locust (Robinia pseudoacacia L.), black walnut (Juglans nigra L.), yellow-poplar (Liriodendron tulipifera L.), northern red oak (Quercus rubra L.), and eastern cottonwood (Populus deltoides Bartr. ex Marsh.), but we still need convincing research for other hardwoods. All researchers agree--"plant large seedlings"--but they don't tell you how big is large. I know specific data are around somewhere; I helped collect a lot of it.

The general importance of site quality and how to measure site index is well established in central hardwoods. To avoid costly mistakes, every practitioner must understand the relation between quality sites and quality production of forest resources. Site classification systems to improve management for multiple-forest resources on large properties are just starting to be developed for parts of the region.

Technology for growth and yield estimates has advanced rapidly with the advent of computers. Old and new data bases in this forest science area have produced a solid foundation to improve inventory estimates and make projections for some forest types. There are some basic data gaps to be completed, and we still need reliable ways to predict quality changes.

There is a large body of information on the principles and practice of managing hardwood stands. Past research has shown what kinds of responses to expect from intermediate cutting in different aged stands from saplings to mature trees. Release cuttings in very young stands to improve composition, growth and quality is risky. Responses in older stands are more predictable and some improvement cutting can be good investments. Some excellent guidelines are available for release, weeding, thinning, pruning, and managing for high quality trees. Research on fertilization has been limited and the potential for practical application is uncertain.

Economics and markets are key elements in the future of central hardwoods. We have some guidelines and advice about making decisions on forest investments. We even hear good news now and then about new and expanding markets for low-quality material. But there is a very large volume of presently unmerchantable material taking up valuable growing space that needs to be removed.

Many agents damage hardwood trees: insects, disease, fire, logging, grazing, and perhaps air pollution. We have some good information on things to do and not to do for some of these agents. For others, such as gypsy moth, we may never have easy solutions. We can certainly do a much better job minimizing damage to soils and residual trees during logging. Experiences in Europe and in the eastern United States strongly suggest that the central hardwood forests should be given high priority in future air pollution research.

Wildlife is often given as a primary reason for owning hardwood forest lands. So forest practitioners need to be able to prescribe treatments to favor both wildlife and timber. There are many treatments that can be made in stands of various ages to improve wildlife habitat. But too few of the prescriptions made by wildlife specialists seem to consider forest practices. And too few prescriptions made by forest management researchers consider wildlife needs. Since managers must make prescriptions that include several resources, they need reliable research results where timber, wildlife, water, and other resources were considered in the design, treatments, and outputs. While multidisciplinary research is certainly not a new concept, there seems to be a resurgence of interest in making it work.

If someone is interested in enhancing recreational opportunities, there are some excellent principles and guidelines to follow. The same is true for owners and managers who want to present a natural appearing landscape for themselves and the viewing public. Suggestions for ameliorating the visual impacts of forest cutting practice make good sense, but we need to see some demonstration of how to get practical technology into use.

Research has provided the basic understanding of hydrologic processes and how water production and quality are influenced by forest practices. We have excellent guidelines on how to protect forest soils and water quality during various kinds of forest operations. Forest roads can be constructed and used with minimum erosion. The impacts of forest grazing are well known by water specialists. The pressing problem in forest hydrology is to better use the information we have

to convince forest owners, loggers and farmers to protect watershed values.

## DIRECTION OF CURRENT RESEARCH

When I saw a copy of the Sixth Proceedings of the Central Hardwood Forest Conference, I was impressed. I was impressed by how big it was compared to the First Conference. I read the whole thing--all 526 pages. I started out reading only a few papers, but they turned out to be so good I decided to "evaluate" the quality of all the papers. I classified each paper as to whether or not it contained new information. Obviously, I am not an expert in all the technical areas involved, so my estimate was probably conservative. I judged that 80 percent of the papers contained new and useful information for me. That is excellent and demonstrates good work on the part of the scientists and Conference organizers. However, if I was right in my assessment, research budgets could have been extended by 20 percent by more careful problem selection. Simplistic, but I am sure many of you have mentally made these kinds of observations at conferences you have attended.

I liked the general format of the Proceedings, especially the invited papers and keynote. Obviously, they were designed to be provocative and to expose the participants to emerging issues. I believe these Conferences are worthwhile and serve a number of good scientific purposes from peer review to exhilaration and enjoyment. They are essential for the process of scientific scrutiny to improve future research and development. Having said that, it is my purpose to make some observations, express my concern, and give some opinions on the needs and directions for better hardwood research.

First, I will continue with some observations developed during the Central Hardwood Notes project, my review of the Sixth Proceedings, and of course the bias I have developed through experience and misadventure.

Forestry research reporting is getting better. I am not sure who is responsible, but in my experience authors, reviewers, and editors are all doing a better job. This is reflected in Proceedings, Journals, and Technical Papers. Yet there is room to improve both technical content and readability. We need better research reporting to improve the acceptance of results by peers and users, to be more competitive for research funds, and to get paid more.

There is still a general tendency to use too many words, include unnecessary information, and be indirect. While proper qualification is essential for scientific reporting, over qualification tends to weaken conclusions and mystify readers. Overuse of citations is burdensome and takes up valuable space. Cite new material and authoritative review articles where possible. Overciting yourself is hazardous unless you are in a very narrow line of research. Too many authors on a report tends to weaken scientific accountability and credit--footnotes are often more appropriate. Peer reviews are many time cursory, and this is often the result of overusing the "buddy system". Good, constructive reviews make big improvements in manuscripts, but they take valuable time. Be prepared to reciprocate.

I don't want to leave you with the idea that I think all research reporting should be how-to-do-its. Scientific reporting is essential to the development of knowledge in any science. My favorite story "on being scientific" is one I tell on myself. Probably my most original research was to clearly demonstrate for the first time that endotrophic mycorrhizae have a beneficial effect on tree growth. I wrote a brief article and submitted it to a new science journal in forestry. They could not use it because it was obviously aimed at foresters and tree planters. So I revised it, made it sound more scientific, and it came out in AAAS's Science with a worldwide audience.

We need to make research problem selection a more rigorous process. There are lots of valid considerations, but the bottom line for both basic and applied research should be who cares? and why? We also need to talk to users, extension specialists, and other agencies before we design studies to be sure that potential results can be directly translated into prescriptions for action. This is a compelling reason for having technology transfer a formal part of the study plan.

Fred Haeussler, past president of the Society of American Foresters and Land Manager for a large forest industry, laid out his concerns for "Application Challenges" rather bluntly in Rochester, New York (1988). Fred said, "Researchers, extension specialists and forest managers don't communicate as well as they should. They don't coordinate their efforts as well as they should. They don't work together in close harmony with joint goals and objectives." He believes there needs to be closer, more open and constructive selection of research priorities.

If a major conclusion is "more research is needed", show why more resources will provide some useful technology. We often fail to point out the practical significance of research results. Many hardwood researchers are too modest about their research; maybe not all of them but at least some of them. Depending upon the audience and outlet, we need to be more aggressive in suggesting how to use new information even if the results are short term, preliminary, or basic in nature.

Sometimes we forget or ignore lessons from the past and do research where it is convenient, not where it is proper. If you do research on artifact sites, you will get artifact results. Black walnut studies on thin, poorly drained soil will produce thin, poor results. After all, we have been hearing off and on since at least 1878 that walnut needs deep, rich soil (Hough 1878).

PRIORITIES FOR HARDWOOD RESEARCH

The publication Research Priorities for Eastern Hardwoods (McLintock 1987) is a definitive source of information on research needs for central hardwoods. It includes priority ratings at the problem area level. It is comprehensive and it is good. Many of you provided input. All hardwood researchers should carefully consider these recommendations when selecting new study areas. Naturally, there are other factors you must consider when setting priorities, such as expertise, support facilities, cooperators, funding levels, time spans, and assignments. Never be timid about expressing your ideas about research priorities after objectively considering the factors and the opinions of others. In my experience, creative ideas are scarce and are rarely squelched.

The same rationale applies to the misapplication of existing technology. All too often we see mistakes by people who should know better. I was asked to look at a bottomland walnut plantation that was failing. The soil scientist said he had taken several soil cores on the site. But he didn't get far enough off the road and the bench it ran on. When we got to the site and opened the car door I knew the answer. You could smell "crawfish land" and you didn't need a lot of soil cores to know what was in the soil profile.

There is no need to improve on McLintock, but I would like to share some of my personal concerns about funding, priorities, and the future of the hardwood resource.

I heard an estimate that the amount of research in the United States more than doubled from 1976 to 1986. In sharp contrast, the number of forest scientists decreased substantially during this period. Giese (1988) traces the decline in funding during the past 10 years and calls forestry research "An Imperiled System." Realistically, other priorities were judged to be more important than ours. We simply did not compete. We can and must do better in demonstrating needs, capabilities and opportunities for better returns returns on investments in forest research. We need to be more aggressive and more urgent about some of our high priority problems.

In the world race for leadership in biotechnology, forestry is getting off to a very slow start. There are valid reasons why most of the support for this kind of research is put in such areas as medicine and food. But there are exciting possibilities in trees, and we need to find ways to capitalize on this developing technology.

Do we have an imbalance between short-term and long-term research? I think we do, and it is leading to serious problems. First, both kinds of research are essential in developing appropriate alternatives for the management and use of forest resources. A lot of short-term research has provided us with a good understanding of the silvics of major tree species. We must continue to learn about other species as well. In the past we did not overlook long-term research, but it took a lot of resources and we took a lot of shortcuts. In fact, some long-term research is more accurately described as case studies. The trouble with case studies is that forest stands and situations are dynamic, and they change and case studies become artifacts of forests past. But we have learned a lot from case studies, and we will continue to learn from them. Fortunately, we still have some well-designed long-term research that is still technically active. But with the pressure on research budgets for the past 10 or more years there have been a lot of changes made in the status of various Experimental Forests and long-term research projects. I do not question the wisdom of all the decisions that had to be made, but I suggest that we must find ways to adequately maintain and significantly expand long-term research to develop in-depth treatment-response data sets. We need to make a better case for the usefulness of interim results in long-term research. We have some excellent examples where this was done, but we also have examples where we were not aggressive enough.

Researchers and especially research administrators always say we need more research, which means more money. Why more long-term research? We have reached a point where we must pay more attention to forest systems and forest ecological processes if we are going to find dynamic solutions to dynamic problems. For example, we have yet to resolve a number of important questions for different silvicultural systems including uneven-aged systems. If we do not do more substantive long-term research we will continue to recycle research, reinvent the wheel, and relearn what we already know. We do too much of that now. Let me give you a real example--oak regeneration.

Korstian (1927) and other early American writers gave us the clues to oak regeneration--advance reproduction. The prescriptions for cutting were European but essentially untested in this country. Not to worry, there is plenty of oak in the understory and the overstory. Ivan Sander and I summarized a lot of long-term research in the late 1960's and took a close look at what kind of reproduction we were getting. Not to worry, most of the time we were getting enough oak. But the closer we looked the more exceptions we found. We now believe that there will be more and more exceptions as the stands continue to change dynamically as a result of some dramatic changes in land use. So we know advance oak regeneration is important but we don't know for sure how to get it. Richard Watt and I summarized the collective wisdom of oak researchers in 1971 (Clark and Watt 1971) and proposed how to reproduce oaks without having actually done it. Our recommendations still sound good. In the meantime, Ivan Sander and associates have continued their long-term research to find out the facts. They have generated a lot of basic information and some practical guidelines, but in their expert opinion we still must continue long-term research on the oak regeneration process. I believe them.

All of you oak researchers and managers remember this: oak regeneration is a long-term process and not an event. Problems in oak regeneration are discussed in recent publications by Mills, Fischer, and Reisinger (1987); Coder, Wray, and Countryman (1987); and Crow (1988).

With the technology now available for data collection, storage, summary, and retrieval, the costs to maintain long-term research records can be substantially reduced. Through cooperative efforts we should extend the coverage of such research to include the major associations and conditions. Funding is a significant problem, but we need to start thinking about how to do it and where to do it. At the same time, we need to correct some inequities in the reward system for those engaged in long-term research.

For several years there has been a call for more multidisciplinary research. There may be some in the pipeline, but I have not seen much evidence that we can expect to see estimates of multiresource outputs designed specifically for that purpose. As we take on the more complex job of studying forest ecological processes, we must use multidiciplinary teams to evaluate multiple resources. Many central hardwoods owners and managers have multiple objectives. So far, we can only guess at or synthesize outputs other than timber. Considering the possible permutations that could result from various sites, types, ages, and stand conditions we may never be able to make finite estimates of multiple resources. But it certainly makes more sense to use appropriate expertise when a study is designed and executed.

In discussions of research needs, someone always recommends that we need to be able to prescribe some extensive treatments. This is good advice considering the long periods of investments and the relatively low timber value of many hardwood stands. We do need low-cost treatments to establish desirable regeneration, to favor the best species in young stands, and put the growth potential on the most valuable trees. Biological alternatives must be accompanied by valid costs and returns.

There are a lot of other technical areas with high priority problems that need to be solved before we make the central harwood region fully productive for multiple uses. Without more effective utilization and better markets we will not be able to use the vast amount of excellent wood and fiber in low value trees that could be converted into high quality parts or products. This will require a lot of research and development in logging, processing and economics. How can we capitalize more on potential international markets while we strengthen the domestic industry? We still have a lot to learn and better guidelines to develop for both natural and artificial regeneration for many of the hardwood species. We will continue to lose and fragment forest acreages and habitats to stripmining unless we can make a better case for reclamation with trees. We have a good foundation in growth and yield research, but we need to include more sites, species, quality, and time in our studies. Insects and diseases will be here as long as we have trees, and we need to know how to manage stands that are healthy enough to withstand the rigors of outbreaks that are sure to come. If we don't hurry up and learn to use fire as a cultural tool, we will lose it as an option. We know that timber cannot bear all the costs of ownership. We need better prescriptions for integrated management based on multidisciplinary research that will increase the quality and quantity of recreation, wildlife, and water as well as wood products. And owners and users tell us that is what they want.

That sounds like more than enough for all of us to do for quite awhile. That is why it is important to select high priority problems, get all the help you can, don't duplicate, and don't dally.

## AND THAT'S NOT ALL

As Yogi said, "It ain't over till it's over." You are not done with your research until it is put into practice. Getting research results into use by individuals and agencies is a significant part of your job or at least it should be. There is another very good reason to get your research results applied--self preservation. Nothing begets funding better than highly visible success.

While I am giving advice, I would like to add a few more things for each of you to consider and support:

1. We need to support a strong and viable domestic forest industry.
2. We need to improve habitats for both consumptive and non-consumptive forest wildlife.
3. We need to improve forest esthetics and recreation.
4. We need to protect forest water quality.
5. We need to help develop a stronger forest land use ethic with longer ownership tenure.

I hope I have not left you with any feeling of pessimism. On the contrary, I am optimistic. The central hardwood forests certainly look a lot better than 40 years ago. The forest survey data show tremendous inventory increases. True, it is harder to find the very big trees, but that too can change with more time. When we get done with all the jobs in front of us, the forest will have changed so much that future researchers will have a new set of problems and opportunities. And that is not to say we did our jobs wrong. It will be because we did our jobs right and kept the forest dynamic.

To close I would like to share with you the last stanza of Cleo Caraway's "Sacred Trust" that opens the Central Hardwood Notes.

"For those descended from the settlers
Of three hundred years ago,
All the plants and living kingdoms in the regions of the hardwoods
Are a trust to be conserved,
To be improved, to be restored,
All the woodland populations are a trust to be restored
For the peoples of our nation,
For the peoples of the world."

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# CENTRAL HARDWOOD FOREST RESEARCH BUDGETS, PRIORITIES, CHALLENGES[1]

Ronald D. Lindmark[2]

Abstract.--The North Central Forest Experiment Station is committed to maintaining its role in central hardwoods research. The key to our success, and our most important challenge, is to continue the legacy of conducting productive, meaningful science. Toward that end, we are working to maximize our partnerships with other Stations, universities, State agencies, corporations, and other organizations.

It didn't take much effort on the part of the conference organizers to convince me to participate. Alums always like to return to their alma mater, and that's how I regard Carbondale. I was a project leader at the lab from 1969 to 1974. Those good years bring back many fond memories.

But a more compelling reason brings me back to Carbondale this morning. This conference gives me a forum to express my pride in the accomplishments of our Station scientists and cooperators who conduct central hardwoods research.

When I worked here, we had 5 research projects, 15 to 20 scientists, and an army of technicians and support personnel. Those were days of expansion; big budgets and lots of personnel. It was easy to be a scientist then.

Doing productive science in today's climate of tight budgets is not easy. Yet, despite adverse conditions, our scientists have continued to produce. I'm glad to have the opportunity here to celebrate some impressive research accomplishments and to congratulate the scientists responsible for these accomplishments.

I spent many years in the Forest Service's Washington Office with Bob Buckman, then Deputy Chief for Research. I'll never forget one of Bob's favorite sayings to Staff Directors, Station Directors, or others who came into his office seeking support, solace, or advice about budget problems. "Damn it, don't tell me what you can't do with the budget you have, tell me what you can do!" Bob used to say.

The work of our scientists today is testimony to what can happen when we avoid the destructive temptation to develop a chip on our collective shoulders bemoaning the resources we don't have, and instead to make the best of what we do have.

So before I go any further, I salute the men and women, at the Station as well as at other research institutions, whose good work under not so ideal conditions has made it possible for us to convene this symposium. They've engaged in PRODUCTIVE SCIENCE, and after all, that is what we're all about. It's too easy to lose sight of this basic foundation of our business. I want you to know that I think the most important mission of my job is to support and encourage productive scientists in as many ways as I can.

I'm proud of our work in black walnut silviculture, protection, genetics, and management. I'm also proud of the accomplishments our scientists have made in hardwood processing, such as basic research involved in understanding the principles of drying. Our scientists in Columbia have created a valuable body of knowledge regarding oak regeneration, critical to the management efforts of National Forest personnel. I'm especially pleased with our exciting technology transfer efforts like the Central Hardwood Notes, which will be coming out soon, and the Walnut Notes, which have just been published.

I'm not only proud, but also very impressed by this record of achievement. It's fair to say this work is the reason our laboratories and scientists in Carbondale and Columbia are considered leaders in the field of central hardwoods research. I want you to know that I'm dedicated to maintaining this record of achievement.

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[1]Paper presented at the 7th Central Hardwood Forest Conference, Southern Illinois University at Carbondale, March 5-8, 1989.

[2]Ronald D. Lindmark is Station Director of the North Central Forest Experiment Station, St. Paul, Minn.

With that said, let me mention several topics I'll discuss this morning. First, I'll review North Central's research budget. Budgets are a fact of life in deciding what we do and don't do. Since leaving Carbondale, it seems like a good deal of my time has been devoted to budgeting. I'll talk about our research priorities and the recent organizational changes in our central hardwood research program. Finally, I'll discuss emerging issues in forestry and how the North Central Station is addressing these issues.

Recent Forest Service research budgets, as most of you know, are not a good news story. The budget formulation and development process has become increasingly frustrating during the past decade. After much internal negotiations, our Station proposals, however modified, become part of the total Forest Service research budget. That budget, again after much negotiation, becomes part of the Forest Service budget, then the Department of Agriculture budget, and finally, the President's budget after reductions recommended by the Office of Management and Budget.

The legislative budget process also goes through many iterations to finally produce what during the past 8 years has been additions to most budget line items reduced in the President's budget. However, all restorations have been earmarked for specific programs and specific locations, mostly for high priority programs such as acid rain. In addition, our budget is rarely received on schedule and frequently comes as a continuing resolution late in the fiscal year. If you've ever seen a yo-yo in action, you have a fair idea of our budget process.

The bottom line is Forest Service research budgets have declined. This is true both nationally and at the North Central Station, especially when we allow for inflation and increasing salary costs.

North Central Station employees need to look no further than their own operations to see the effect on our research programs. In 1978, the Station had about 100 scientists and almost 250 permanent full-time employees. Today, a decade later, we have 70 scientists. We are simply not holding our own when it comes to budgets. And all this comes at a time when the cry for scientific knowledge is increasing.

Tight budgets and mounting costs have forced us to closely examine our programs and our priorities. If I can leave you with one thought this morning, I hope it's that the North Central Station cannot meet the forestry research needs of this region alone. We simply don't have the resources to tackle the great array of questions involved with the diverse resources in the North Central Region. It has always been important, but in today's economic environment it is critical that we maximize our partnerships; our cooperative relations with other Stations, universities, State DNR's, individual corporations, and other interested groups. No one likes reduced budgets. But I prefer to look at the positive side. Tighter dollars will motivate us to foster better ties with our research clientele.

Congress and the Washington Office recognize the need to look for outside funding sources to supplement federal dollars. They're encouraging us to do this very thing through cooperation and partnerships with non-federal organizations. One example is the research challenge cost-share program. In this program federal research dollars are matched to non-federal research dollars made available to study a particular problem. The aim is to make the most of federal research dollars. This year $500,000 has been made available, providing we can obtain matching funds. Another $500,000 has been proposed in the Reagan budget for next year. We don't know if President Bush will modify that.

The Station has responded to this incentive. This year we submitted 26 proposals for almost $500,000. We haven't heard yet which proposals have been accepted, but of course, we hope to get a healthy share of this money dedicated to research at the North Central Station. This is a new experience for us, but it is an opportunity for both the federal and private sectors to strengthen our research effort.

We must continue to be aggressive and imaginative in strengthening existing ties and in establishing new relationships. This is an important part of getting the job done. We value the cooperative relations we currently have with SIU, the University of Missouri, the Black Walnut Council, the University of Illinois, and the University of Wisconsin, to name just a few. I see this as the norm in years ahead.

What are the research priorities at the North Central Station? Much of the North Central Station's territory lies within the central hardwood region. Central hardwoods research has always been a major research emphasis at the North Central Station, and it will continue to be.

Our three central hardwood research projects involve 11 scientists based at two locations. We have two projects at Carbondale: the Central Hardwood Physiology and Genetics project led by Jerry Van Sambeek, and the Hardwood Processing unit led by John Phelps. Our other central hardwood research project is based in Columbia. That project, Central Hardwoods Silviculture and Ecology, is led by Steve Shifley. Combined, this research consumes 27 percent of the Station's total timber management research budget, 13 percent of our total Station budget, and 16 percent of our cadre of scientists.

Considering the diversity in our programs, these numbers show that central hardwoods rank

high in terms of North Central's research programs. This is especially true when we consider that other programs such as Forest Survey, which we are striving to get on a 10-year cycle, consume 1/5 of our resources. I think it's also important to note that our Forest Survey project and our Station's economic studies apply directly to the central hardwood region.

I'd like to discuss research priority setting in a broader context. I'm often asked, "What are your research priorities?" for any number of topics. Unfortunately, priority setting is not a simple, straightforward process.

At least four factors influence what we do. (1.) National research priorities established by the President through our Washington Office and by Congress. (2.) Local research needs, as described by both private and public resource managers. (3.) Budgets. As I alluded to earlier, Congress is becoming increasingly activist. They use earmarking and specific budget allocations to implement their own agendas. As I mentioned, our budgets are given to us already broken down by budget line items, and any restorations are made to specific locations. We have a little flexibility to reallocate funds, but not much. (4.) Scientist skills and research equipment, to a lesser extent. Our research is determined somewhat by the skills and inclinations of our scientists, although we can manage our work force to minimize this to some extent.

The process of how any one or a combination of these factors determines specific programs differs by Station, project, budget year, and Congress.

Each of our three projects is working on priority problems identified by us and a number of user groups, such as the Hardwoods Research Council. I value highly the advice and suggestions made by these outside groups, and I look forward to working with them in the future. An analysis of the research problems and an assessment of our resources led us to restructure our Carbondale and Columbia efforts. With planned retirements, termination of a unit in St. Paul, and salary savings through reductions in our technician work force, we feel we are focusing our very limited resources in Carbondale and Columbia.

We've tried to eliminate any overlap in our timber management research. We also have tried to give each unit a clearer mission. The work at Carbondale will focus on plantations and on the fine hardwoods. The work at Columbia will deal with natural stands and with a more holistic, multi-functional approach to central hardwood ecosystems. We think this split will make us more responsive to user needs and better position our Station to compete for TMR dollars. We welcome support to strengthen the programs at both locations.

Before I shift gears, let me review. Declining budgets have forced us to examine our programs, make a lot of difficult choices, and to seek productive partnerships with our clients. Despite tight budgets and many research demands, we will continue to expend a significant amount of our Station's resources on central hardwoods. The recent reorganization of the central hardwoods research program will make us more efficient and competitive for research dollars.

I'd like to talk about emerging research needs and how they relate to traditional long-term studies. Forest Service research has maintained continuous research plots, on growth and yield, for example, for longer than some of the famous European forests. Most of these plots, found on our experimental forests, are invaluable.

We're committed to maintaining them. Again, budgets might not allow us to expand these studies, and we may be forced to convert some research plots to demonstration areas if we can't justify usefulness. But for most of these studies a maintenance, bare-bone level of support is usually possible, even after the hard choices are made. To survive the close inspection tight budgets demand, such studies must be able to demonstrate productive, tangible results.

In fact, productive research is really the key to our success at the broadest level. The best way to foster support of our programs is to produce high quality research that makes a difference--that is needed and will be used by our clientele.

In a similar vein, if we want to be "in the loop" on emerging issues, we've got to be poised and ready as an organization to respond quickly and effectively to emerging issues.

What are these issues? Such things as global climate change, including the effects of atmospheric deposition; water quality; economic opportunities through new forest products; threatened and endangered species; and catastrophic forest fires.

How do we prepare to respond? We examine how our current research might be applied, or modified, to become pertinent to these concerns. We look for new partnerships, and added financial support, with groups concerned about these same problems. We keep our programs flexible. Our scientists no longer have the luxury of spending entire careers on one very narrow subject area. Today, we must be willing and able to re-focus our research orientation to respond to changing needs. Research at both the Carbondale and Columbia labs should be aware and sensitive to local and regional issues of this sort.

An important part of "productive research" is technology transfer. We've simply got to commit ourselves as scientists to ensuring that

what we learn through our work is communicated to natural resource professionals.

I think we've done a pretty good job of technology transfer. The Walnut Notes and Central Hardwood Notes I mentioned before represent state-of-the-art information.

I'm particularly proud of the effort, creativity, and innovation that have gone into these publications. More than 50 years of research results and experience from natural resource professionals and researchers have been condensed into these for use by natural resource managers. Forest Service retiree and former boss Bry Clark deserves much credit for the Central Hardwood Notes. Authors include scientists from universities, government agencies, and industry. I think these publications will become required reading for any professional manager, and the looseleaf format will enable us to update the information they contain.

We're also putting the finishing touches on a walnut demonstration area. When completed this summer, this site outside of Carbondale will give managers a view of different silvicultural practices related to black walnuts.

We value our association with user group organizations, partly because these associations are an excellent way to transfer research information. We hope to maintain and strengthen our ties with groups like the Hardwood Research Council and the Walnut Council.

Finally, workshops and symposiums like this are an important way to discuss and publicize our research results, and seek the support we need to forge ahead. I want to thank the organizers of this symposium. I know it takes a great deal of effort and time to organize this. George Rink, and all the other members of the organizing committee, thank you.

These technology transfer efforts can also make our clients familiar with existing research information that applies to current issues. For example, we have a great body of knowledge on oak management and oak regeneration. Yet National Forest personnel in this area are really struggling with the issue of oak management and clearcutting.

It's easy to say we already know how to regenerate oak. It's harder to take this information and apply it to their management situations. We all know that National Forest personnel and other land managers don't manage in a biological isolation chamber. Economic, social, and political pressures often demand less than biologically optimum management practices. I think technology transfer efforts must recognize these pressures. We need to look at how our information can be applied to their situation.

But again, at risk of repeating myself too often, these technology efforts are based on the assumption that our research results in new information, new and improved ways of doing business that make a difference.

Let me sum up by giving you my vision of where the research at the North Central Station is going. We will continue to try to fill existing technical gaps in our knowledge. Answers to some of these questions will come from basic, fundamental research. Other problems will dictate applied work. Both facets are addressed at Carbondale and Columbia. We will do more cooperative research. Our programs, to survive and gain support, must become more flexible, more able to change to respond to emerging issues, like global warming. This demands that our scientists be able to switch gears occasionally. The nature of funding our work makes the attribute of flexibility even more important. Our work will come under closer scrutiny by legislators, research clients, and the general public. The best support we can obtain is the testimony of pleased clients.

To survive, to even thrive in this climate, our work must become increasingly productive and of demonstrated value. We have to continue to work hard in our laboratories. But as importantly, we must work harder in the public arena, and in our efforts to apply our research information in ways that make our research information contribute to solving management problems and concerns.

If we do this, we'll be better poised to meet the challenges of the future.

FORESTRY RESEARCH FOR ILLINOIS: RECOMMENDATIONS OF THE ILLINOIS COMMISSION ON FORESTRY DEVELOPMENT[1]

Gary L. Rolfe[2]

Abstract.--Research recommendations were developed by the Illinois Commission (Council) on Forestry Development for Illinois and central hardwoods in the context of national issues and priorities. Recommendations are a combination of reactive/proactive research initiatives integrated with landowner educational needs. Included is research on management options, enhancing multiple use, woodlot productivity, agroforestry, expert systems, private landowner goals and motivations and environmental issues. A statewide computer network and resource database and a comprehensive educational program is recommended to facilitate effectiveness of these research initiatives.

Productive forestlands are integral to the economy of the United States. With nearly 737 million acres of forest cover in the U.S., the production and maintenance of these lands is very important (Bentley 1986). Forest-based industry alone contributes more than 60 billion dollars annually to the U.S. economy and employs 1 of every 11 people in the manufacturing industries (Brown 1986). Couple these direct economic gains from our forest resource with the inestimable value of the resource for recreation, wildlife, soil and water conservation and its contribution to global atmospheric stability and it is easy to justify a well-financed and broad-based forestry research program. Such a program could provide the basic information needed to effectively manage this critical resource for the long-term.

Unfortunately, our forestry research programs have not kept pace with the significant need for information to effectively manage the resource. Currently, our University-based forestry research program nationwide totals less than 100 million dollars annually (Brown 1986). Industry-based forestry research programs are generally declining and the Forest Service program is only stable at best.

Although support for forestry research is not in keeping with the value and importance of the forest resource it is perhaps a less significant factor than the implicit nature of our research programs. Often, our research initiatives are driven by "crisis" situations. In other words, our research programs tend to be predominantly reactionary to meet specific problem situations encountered today. We are generally unable to channel research resources into a more long-term or proactive approach because of financial limitations and the need to quickly deal with providing the information needs of today (Brown 1986). An adequately financed research program could help to stimulate an anticipatory, proactive approach to our forestry research but funding is only one limitation. The forestry research community may, in fact, be another limitation because of our generally conservative attitude. We must be more aggressive in our forestry research and move into a proactive position which projects from today's database and today's issues into the future to predict tomorrow's needs. Certainly our research programs will always have a reactive component because not every issue can be predicted but we must move aggressively to establish a longer term view of the resource to ensure its future viability and contributions to society.

The Illinois forest resource picture is quite similar to the national one. Illinois has more than four million acres of some of the most productive forestland in the midwest but this important resource suffers from neglect (Rolfe and Richmond 1986b). The majority of our forestlands are privately owned and in relatively small parcels averaging less than 50 acres each

[1]Paper presented at the Seventh Central Hardwood Conference, Carbondale, Illinois, March 5-8, 1989.

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(Herendeen and Rolfe 1983). Currently these forestlands are producing about 144 million board feet annually but this is less than one-third of their capability (Rolfe and Richmond 1986a). The Illinois forest industry which is a one billion dollar industry can only benefit from improved productivity and management of Illinois forestlands.

Illinois now ranks in the bottom 10 states in wood production but near the top five states in wood use (Rolfe and Richmond 1986b). Narrowing this gap between production and use could result in significant gains at every level of the Illinois economy. Improving productivity through improved management of our forestlands can also increase the complimentary benefits we derive from our forest resource (Forging a Forestry Future in the Midwest 1983). Better management will result in improved diversity of wildlife habitat, enhanced recreational opportunities and significant soil and water conservation benefits.

Improving productivity on Illinois forestlands and consequent industry development is a challenge which requires a combination of a solid research database with effective landowner and public education programs. To meet this challenge the Illinois Commission on Forestry Development was created by the Forestry Development Act which was signed into law in 1983 (Rolfe and Richmond 1986a,b). The Commission (now a Council) is responsible to the state legislature and has the broad goal of evaluating the Illinois forest resource and making recommendations for development of this resource to meet the multiple public benefits only it can provide--timber, wildlife, recreation, aesthetics and soil and water conservation. Critical to realizing the full magnitude of these multiple forest resource benefits is a proactive research and education program. The Commission through its study of the Illinois forest resource has identified research and education needs integral to achieving this important goal. These research and education recommendations were developed in the context of both Illinois and national forest research needs and are a viable combination of both reactive and proactive approaches to both research and education.

## NATIONAL RESEARCH NEEDS IN FORESTRY

To provide background perspective for the Illinois Commission on Forestry Development research recommendations it is necessary to consider important national research issues. These national issues are an integration of research needs developed through the work of several organizations including the National Association of Professional Forestry Schools and Colleges, the Joint Council on Food and Agricultural Sciences (Five-Year Plan on the Food and Agricultural Sciences, 1986), the Hardwood Research Council (McLintock 1987) and others.

National research issues the Illinois Commission considered as background included:

### Forest Productivity

While the United States has an abundance of total forest cover, productivity on the majority of these lands is considerably below potential with most regions of the country averaging only one-third to one-half of potential sustained yield. Intensive forest management including tree improvement, site preparation, reforestation, advanced silvicultural techniques and advances in harvesting technologies is needed. An expanded research program in these areas is critical. However, productivity increases should not be at the expense of the other benefits provided by our forests or at the expense of environmental quality. Concurrent research should evaluate these related environmental issues.

### Products Development

The recent trend in composite products from wood gives rise to the need for a long-term view of the potential for forest products. New and creative uses of wood must respond to the public demand for new and improved products. The potential for chemicals from wood is largely untapped and new technologies will allow greater sophistication in the use of wood. A comprehensive expansion of products related research is recommended.

### Marketing

Improved marketing systems must be developed in anticipation of public needs and demands. Research in development of wood-based products to meet these demands must be pursued now in anticipation of future public needs. International marketing and global trade issues must be studied and the role of our forests in meeting global needs more clearly defined.

### Biotechnology

Application of biotechnology and high technology techniques to tree improvement for a multitude of goals is viable today and must have a high priority in research. Substantial gains in tree improvement can result from an expanded research program in this area.

### Environment

Environmental issues relating to forests and productivity will continue to come to the forefront in research priorities. Atmospheric deposition, global $CO_2$ cycling and the "greenhouse effect", soil and water conservation, air quality and other related issues are of immediate concern.

### Integrated Pest Management

Forest insects, pathogens and other pests in many forested areas of the country cause tremendous tree losses which can be as high as 20 percent of total production. More research is needed to emphasize integrated use of a range of

techniques including combinations of chemical, biological, biotechnological manipulation, and cultural practices to protect our forest resource.

### Urban Forestry

Specific research programs must be implemented to effectively deal with the expanded demand for urban forest resources. Species selection and management systems as well as a better understanding of the needs of urban citizens are important issues to receive increased attention.

These issues and other more specific research questions at the national level served to provide background for formulation of the Illinois Commission on Forestry Development research recommendations.

## ILLINOIS COMMISSION ON FORESTRY DEVELOPMENT RESEARCH RECOMMENDATIONS

The Commission reviewed research programs of the University of Illinois, Southern Illinois University, other midwestern universities and the U.S. Forest Service, North Central Forest Experiment Station and its branches to determine the current status of the research knowledge base in terms of this previously described broad national picture. Several research issues were identified as high priority for new or expanded research for our Illinois research program. A combination of a reactive approach to deal with current issues and a proactive approach for long-term planning is suggested. The Commission believes that it is especially important that we become more proactive in our research to develop the predictive capability needed to anticipate future resource based societal issues.

Important research recommendations of the Commission (Rolfe and Richmond 1986a,b) include:

### Statewide Forest Inventory and Resource Database

Although only indirectly a researchable issue, maintenance of a current forest resource inventory and creation of an on-line computer database are integral to an overall effective research program for Illinois forests. A comprehensive resource database is essential to development of the productive capability we greatly need.

Previous inventories of Illinois' forest resources were conducted in 1948, 1962 and 1985 by the U.S. Forest Service. However, there is no provision for an ongoing, uniform method of collecting comprehensive data. Existing data offer insufficient detail for the needed proactive approach to long-term resource planning.

It is recommended that a comprehensive urban and rural forest inventory be conducted at regular 10-year intervals to provide management agencies, forest researchers, members of the timber industry, and other concerned groups with current, usable information. New techniques such as satellite imagery interpretation should be incorporated and utilized as appropriate.

It is further recommended that an on-line forest resource database be created and maintained with up-to-date forest resource information. This computer database should be part of a statewide network and easily accessible to agencies, forestry professionals and researchers.

### Management Options

Forest management practices have major impacts on the forest resource and the benefits available from Illinois forestland. Impacts of the management option chosen may not be readily apparent for many years but yet have a direct relationship to the benefits the landowner and the public ultimately receive from the forest.

The Commission recommends an expanded research program to evaluate and develop predictive capability of the consequences of a variety of hardwood management options and silvicultural practices. Studies should be designed to develop predictive capabilities of impacts to all relevant forest resources including timber, wildlife, recreation, soil and water conservation, and aesthetics. Consequences of a variety of management practices in urban setting should also be included.

Long-term economic predictions and simulations must be an integral part of this research program in management options. In many instances a clear economic forecast could encourage landowners to institute a comprehensive forest management program.

### Enhancing Multiple Use

The forests of Illinois provide a variety of benefits and as a consequence, are managed for several different uses. Individual landowners often have non-timber production goals but ultimately sell their timber.

Research is needed to develop management systems which optimize multiple benefits. Management systems should be developed which enhance the landowners major goal but also provide the other multiple benefits only our forests can provide. In some instances, multiple uses may be in conflict, so research must be developed in a systems approach to achieve the maximum benefit for the landowner and society.

### Woodlot Productivity

Research on maximizing forest productivity while maintaining a stable ecosystem is especially important. Illinois forests can show

greatly improved productivity with good management techniques but this should not be accomplished at the expense of a quality environment or greatly reduced multiple benefits. A comprehensive expansion of the current research program in woodlot productivity is required. Development of predictive capability for assessing long-term productivity and environmental impacts of improving productivity is essential.

Genetics and tree improvement research utilizing new bio-technology techniques must also be expanded. Genetic manipulation at the molecular level offers a tremendous opportunity to improve productivity without impacting environmental quality or long-term site productivity. Disease, pest resistance and impacts of environmental stress may also be greatly minimized through genetic manipulation.

### Agroforestry

Current research programs to develop agroforestry systems for Illinois marginal lands should be expanded. Illinois has nearly two million acres of land which is clearly marginal for rowcrop agriculture. These lands should be quickly brought into permanent cover but landowners often face a severe financial limitation in taking these lands out of rowcrop production. Agroforestry systems allow the landowner to gradually retire his land from rowcrop production while establishing a forest production system. These techniques are essential for adoption of forest practices by many Illinois landowners.

### Expert Systems

Further research in the development and techniques for implementation of computer-based expert systems to assist private forest landowners in better decision-making is especially needed. With the shortage of forestry professionals in Illinois it is very important that we move towards systems which are easily accessible by landowners and which can provide decision-making techniques. Expert systems coupled with a resource database and a statewide computer network should greatly improve our ability to manage the Illinois forest resource. Forest growth simulation and yield as well as economic scenarios should be an integral part of these systems.

### Private Landowners

With 93 percent of Illinois forestlands privately owned by more than 110,000 landowners it is critical that we fully understand landowner goals, motivations and interests to facilitate good management on their forestlands. Expanded research is needed to further our knowledge of private landowners and their role in development of Illinois forest resources.

### Environmental Issues

Environmental issues are at the heart of a comprehensive proactive research program for Illinois forestlands. In each of the previously described research areas it is very important that adequate research be conducted to provide current and projected environmental consequences of prescribed forest management practices. It is also important that we develop a better understanding of the specific roles of forests in maintenance of air and water quality.

Beyond these major research areas there are many silvicultural issues which must be better understood. For example, the statewide evidence of "hard maple takeover" and techniques to promote oak regeneration continue to be of great concern. Research in new and expanded uses of wood; especially low quality wood and sawmill residues is very important and must continue. Marketing techniques for landowners and primary industry must also be developed and involve a significant research element.

It is very difficult to separate research needs for Illinois forestlands from the overwhelming educational needs of Illinois landowners, the public, and public officials. The Illinois Commission, in its study of resource education programs, found that our programs are considerably inadequate to meet the needs of both the rural population and the urban community.

A basic educational framework is provided by the Illinois Cooperative Extension Service and the Department of Conservation Division of Forest Resources but both are greatly understaffed and unable to provide the needed broad-based forest resource education. Forest landowners require a comprehensive program to educate them on the multiple benefits available from their forests and how to achieve those benefits. These types of educational programs must be based on the proactive research program previously described. Landowners need to know how specific management actions today impact tomorrow's forest and environment. Development of predictive capability involving all of the multiple benefits to be derived from our forests is essential.

The process of educating these forest landowners also requires basic research to determine landowner motivations and goals and how to best work with them to encourage good forest management. Educational programs must be designed to provide the types of information which can have maximum impact on the management of the Illinois forest resource.

The urban community has even greater educational needs with 83 percent of the population or 9.5 million people living in Illinois urban areas (Rolfe and Richmond 1986a). Urban citizens are the predominant users of our forest resource. Resource education programs for

this important group are equally essential if we are to effectively manage our forest resources for multiple values over the long-term.

It is imperative that Illinois forestry research programs are based on the needs of the public but they must also include a strong proactive element which is so very important to long-term maintenance and enhancement of the total forest resource. Continued reliance on reactionary research efforts and relatively low levels of funding for forestry research in Illinois will not suffice to promote and protect our forest resources over the long-term. The Commission strongly recommends a significant expansion of the research programs at the two state universities and encourages the U.S. Forest Service to expand research relating to central hardwoods. The Commission also encourages researchers in Illinois to develop complementary, interactive programs to realize the maximum gain from our research dollars.

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# CENTRAL HARDWOOD RESEARCH PRIORITIES

# AS VIEWED BY

# A STATE FORESTER[1]

Allan S. Mickelson[2]

Central Hardwoods are an important resource in Illinois as well as in the surrounding states. They are important commodities to the economies of the Central States and important to the worldwide manufacture of fine furniture, fixtures and construction materials. They are also important in terms of their non-commodity values of wildlife, recreation, water and air quality, providing for an overall better quality of life.

Yet as important as this resource is, we have seemingly paid less attention to it than it rightfully deserves. Much greater potential can be achieved through more active management based on sound scientific principles.

Central Hardwoods cover 80 million acres in the eastern United States and represent 33% of the total forest cover. The commodity value of this resource is staggering. Far greater values are associated with the non-commodity and intrinsic values. Further, it has been estimated that with sound and active management of this resource the economic return could be increased by 7 to 10 times the present day values. But status quo will result in losses of a much greater magnitude.

Research on Central Hardwoods is desperately needed and justifiable.

To assist in identifying needed research on our Central Hardwoods, I sought the input of my counterparts in Iowa, Missouri, Indiana and Ohio. Therefore, the perspective I present today on research priorities in the Central Hardwoods is the collective consensus of five State Foresters. I must say that the response to my request for input was handled on an immediate response basis, indicating to me that all State Foresters share a concern that this topic of research on the Central Hardwoods needs immediate attention.

The research need that was identified as being most pressing in the majority of the states canvassed was Oak Regeneration/Hard Maple replacement.

Oak Regeneration: While some of the principles involved are known, we generally do not have good prescriptions on high quality oak sites. There is a need to know how and when to prescribe a shelterwood, group selection or clearcut system of even-aged management operationally with a high or higher degree of certainty. Recommendations developed in the Ozark Region do not apply throughout the Central Hardwood region.

Two aspects of oak regeneration need to be investigated: natural and planted. Past oak high grading has progressed to the point where natural regeneration of high quality oak may no longer be a viable option in many stands.

Tied rather closely to this is the need for additional research to identify and propagate the best oak seedlings, either in the wild or nursery environment, to develop the most economical methods of planting and bringing these seedlings through the rotation to achieve natural stand dominance.

Advances in tree improvement, seed handling, genetic engineering and tissue culture are needed on oaks and other fine hardwoods. These needs are becoming more pressing as the time, costs and space needs of nursery propagation become more prohibitive every year.

Oak Decline: High hazard areas of oak decline have been identified in the Central Hardwood Region. Some treatment measures applied apparently augment the spread of decline symptoms to adjacent stands; however, new research is needed to determine the causes and the correct means of managing these areas to minimize damage.

Hardwood Utilization and Marketing: Additional and/or new research is needed to find profitable product uses for our under-utilized species. These are more commonly referred to as low-grade hardwoods. With utilization and marketing research the profitable use of these species would enhance more active management of our forest stands. Can methods be found to over-

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[1] Paper presented at the Seventh Central Hardwood Forest Conference, Carbondale, IL, March 5-8, 1989.

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come the barriers of utilizing oak, hickory and other "heavy hardwoods" in oriented-strand board or other composition board products? Also along these lines is the need to develop equipment for intermediate stand treatments. Perhaps even more basic is the need for more eocnomical and effective and efficient methods of deadening trees in a TSI operation. The old axe/chainsaw girdling or felling methods are becoming cost prohibitive.

Growth/Yield Information: The lack of growth/yield responses to standard silvicultural practices applied in our Central Hardwood region and the corresponding economic implications of these practices are causing considerable problems. Our field foresters' clientele is constantly improving in educational levels and sophistication in understanding the involvement and activities that affect the environment. More and more their decisions are being based on economic considerations where some type of investment must be made to assure a future return or desired result, as opposed to biological considerations. There is a desperate need for better computer-based growth/yield programs and associated economic analysis software programs.

Uneven-aged Management Systems: Closely related to, yet separate from, the oak regeneration issue is the present uneven-aged silvicultural system we're using to manage oaks. The "q" factor approach is one method of single tree selection but it is difficult to apply. More practical and applicable approaches to using uneven-aged management practices are needed.

Political/Economical/Educational: More advanced research is needed to develop programs and means to communicate the benefits of forest management to the public and to elected officials. The image of forestry, the profession, our programs and practices has been tarnished. More effective means must be found to better represent the "truth of the woods" and our efforts.

Innovative Product Development: A visit to the supermarket by a forester is a disturbing experience. We find plastic milk jugs, meat on styrofoam, cereal in cellophane and all packed from the store in plastic bags and taken home to a formica kitchen. Our land fills are rapidly approaching capacity with a high percent of the material being wood, wood products, paper and wood residue.

Meanwhile, our sawmills are being covered with sawdust and our wood manufacturing plants are being crippled by wood dust problems.

Our wood-based paper plants are being threatened by cultivated short rotation or annual agriculturally oriented crops.

Biodegradable "plastic" bags are now being manufactured from corn products or by-products. Why can't wood by used as well? Wood burned in combination with fossil fuels could substantially reduced the $CO_2$ and $SO_2$ omissions.

New uses of wood and wood residue must be found before the market place goes to synthetics completely.

Urban Forestry Research: We must not forget as we discuss Central Hardwood Research that the same species and some of the same problems are found in our urban areas. Urban forest management is a growing concern throughout the United States. Intensified research efforts are needed. To effectively manage, enhance and expand the urban forests we need a survey to quantify it.

On a periodic basis the USDA Forest Service conducts forest inventories State by State. Yet a vast area of the forest resource is not included in a detailed manner to positively affect programmatic structure. This vast area includes the urban forests of the Nation.

We need additional research on species to plant, new cultivars, insect and disease control, product development from urban wood waste and more effective educational programs for urban forestry.

The above should not be construed to be a complete list of research needs in the Central Hardwood region. Some basic research is being conducted with State or private funds that deserves more time, attention and full research development. These projects include oak underplanting, seedling quality, seedling root morphology, tree improvement, nursery propagation techniques, oak mast production, insect and disease problems and agriforestry among others. The research needs are as diverse and numerous as the species in our forests. The common thread that runs through the Region is that the private landowner controls the vast majority of the forest resource base. Anything we can do through research and development that will encourage the wise use of this land and its products will have incalculable benefits. We, as State Foresters, land managers, and researchers must be the leaders in demonstrating how the latest and best technologies can be incorporated into land management. You, as forest researchers, must be the providers of this information.

By working together in this partnership arrangement we will find our forest lands more abundant, more productive and our resources better managed for future generations.

# A DOZEN RECOMMENDATIONS FOR MANAGING HARDWOOD FORESTS PROFITABLY[1]

J. Michael Vasievich[2]

ABSTRACT. Many landowners don't manage their central hardwood forests. In many cases they may be missing out on opportunities to improve their woodlands and increase earnings. Each hardwood forest and each landowner's goals are different, so specific recommendations are not possible for all cases. General guidelines are given for planning management practices, reducing costs, and increasing revenues to increase profits.

## INTRODUCTION

Money doesn't grow on trees, but many landowners profit by careful management of their hardwood timberlands. They want to get the most from their land without paying too much and without sacrificing the amenities or non-timber benefits. Landowners who manage their stands have more productive and profitable forests. These landowners often have certain things in common, and I would like to focus on some general management practices that lead to greater profits from hardwood forests.

Management recommendations cannot be made which apply to all hardwood forests. Each stand is uniquely composed of trees of different species, ages, and sizes, and each landowner has different goals. Some landowners are interested in abundant wildlife. Some want an attractive forest for personal enjoyment. Others want the highest cash return from their timber. Most landowners want some of each of these. Recommendations for specific treatments must be based on actual stand conditions, strengths of local timber markets, and landowner objectives. Therefore, management activities appropriate for one landowner's stands may be off-base for another.

The following 12 recommendations deal with several aspects of economic forest management--professional forestry assistance, stand cultural treatments, harvesting and regeneration, and financial planning. When combined with professional forestry advice and sound judgment, these recommendations will help hardwood forest landowners increase their profits.

[1]Paper presented at the seventh Central Hardwood Forest Conference. [Southern Illinois University at Carbondale; Carbondale, Illinois; March 5-8, 1989].

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### Recommendation 1. Seek the assistance of a forester for planning forest management.

Mixed hardwoods forests are complex and many biological and physical factors affect their growth and value. Managing these forests requires special skill to achieve timber and non-timber goals. These forests are more difficult to manage than even-aged pine plantations because they may contain dozens of different species. Decisions regarding harvests, regeneration, and stand cultural practices should be made with the help of a skilled forester. All landowners have good intentions for their forest land, but they may miss out on benefits or profit because they overlook treatments that can improve their stands or perform treatments that degrade them and lower profits. Foresters can identify and recommend practices that will enhance and protect forest land and improve productivity.

Technical forestry assistance is available from various public and private foresters. Service foresters, extension foresters, State forestry agencies, and university forestry departments can provide help with many forest management problems for free or at cost. However, the services offered by public foresters may be restricted to 1 or 2 days of work a year on each property. Also, most public foresters cannot mark or sell timber, supervise timber sales, or enter into a fiduciary relationship with private landowners. Generally landowners are referred to consulting foresters for more extensive services.

Consulting foresters provide more diverse and specialized services than public foresters. Most consultants can inventory timber, prepare management plans, recommend treatments to meet landowner objectives, sell timber, contract for and supervise silvicultural services, and provide specialized income and estate tax advice. State forestry offices can provide a list of consulting foresters and the services they offer. Some States have registration or licensing laws for consulting foresters, which provide some assurance that foresters meet specified standards.

Many forest products companies have special Landowner Assistance Programs run by company foresters. These programs are aimed at improving management of private timberlands and enhancing relationships between the company and landowners. They provide a valuable source of forest management services to private landowners, but some companies may ask for a first refusal right to purchase timber grown on enrolled acres.

Selecting a forester is much like selecting any other professional. Consultants act as agents, and landowners must have confidence in their reputation and ability. Foresters should be able to provide the full range of services needed. They should be ethical in representing landowner interests and be technically qualified to apply scientific principles of forestry to accomplish management objectives. Consulting foresters should know their clients' management objectives and help achieve them, whether landowner goals emphasize timber production or other forest outputs.

**Recommendation 2. Concentrate timber management efforts and dollars on the most productive sites.**

Timber production has the highest returns on the best sites -- where trees grow fastest and quality logs are produced in the shortest time. Financial returns are higher on productive sites than on less productive ones because forest management practices cost nearly the same on both types of sites.

The best sites can grow at least a cord of wood or about 200 to 500 board feet of quality sawtimber a year in well-stocked hardwood stands. This translates into average annual earnings of $15 to $50 per acre or more these days, depending on volume, species, and quality of the trees. The faster growth rates on highly productive sites offer earlier and more frequent harvests and shorter rotations. Much potential income is lost if these stands are not managed to focus growth on the best and proper number of crop trees.

All forested acres should not be managed the same. Many treatments on highly productive sites are not economical on less productive acres, largely due to slower tree growth rates. Soil productivity can be highly variable on timber stands as small as 30 to 40 acres. So, careful measurements of productivity are important in deciding how to manage stands, when to manage them, and where. Highly productive sites grow timber faster than other sites, and more intensive timber management is appropriate on these acres.

**Recommendation 3. Manage hardwood forests to produce high quality saw logs of high value species.**

Higher timber quality means greater value, especially for hardwood trees. High-quality trees contain sound clear logs without knots, splits, rotten portions, scars, or other defects. The species mixture in a forest also greatly affects value. Central hardwood forests contain many species, but only a few are really valuable. High-quality oak, ash, walnut, and cherry logs are in the greatest demand and have the highest market values. The best trees of these species may be worth five to ten times more than average logs of less preferred species.

Timber quality can be managed in several ways. The key is to maintain the most desirable species mixture and control stand density to assure good growth rates. Stands should be managed to maintain the proper number of high-quality crop trees of the most valuable species to maximize profits. Understocked stands are less profitable because some growing space is unproductive. Tree growth will increase in these stands with time, but there are few options for increasing productivity.

Overstocked stands are less profitable too because undesirable trees compete with crop trees and slow growth. These stands need to be cut to harvest mature trees, remove competing trees, and provide adequate growing space to allow crop trees to flourish. Eliminate trees that are financially mature or that interfere with the growth of crop trees. Cutting strategies must maintain the proper stand density for quality and growth.

Keep the best quality, but immature, crop trees of preferred species in the stand when partially cutting stands. Select large diameter trees that are financially mature for harvest. The diameter of financially mature trees may be 16 inches or more, depending on species and markets. Rarely are high-quality central hardwood trees financially ready to cut at smaller diameters. High-quality hardwood trees gain the most in value as they mature into larger diameter classes and higher sawtimber grades. Therefore, avoid the temptation to cut trees when they reach the minimum sawtimber diameter of about 12 inches. Trees usually are growing the fastest in value at this time. Harvesting these financially immature trees is costly in forgone revenues.

Never cut the best trees and leave the worst. This destructive practice, called high grading, is common and an assured way of producing timber stands full of low-quality trees of undesirable species. Sometimes this practice is

called diameter limit cutting in which loggers cut all merchantable trees above a certain diameter. The problem is that the most valuable trees above that diameter are cut and all the least valuable ones are left. The eventual result is a forest full of low-value, low-quality trees with greatly reduced earning potential.

Crop trees must be protected from logging damage. Damage to residual trees from careless logging can also destroy the quality of future crop trees. So, select loggers carefully. Only accept those with a good record, and be sure to monitor logging progress to prevent damage to the site and the residual trees. A lot of money can be lost when a high-value tree is scarred by logs being dragged behind a skidder. A professional forester can be invaluable in helping to select a reputable logger and supervise logging operations.

Optimum cutting strategies depend on many factors, and there are no simple rules. Adequate timber cutting prescriptions require an examination of each stand by a forester. Many decisions are needed -- how often to harvest, how many trees to remove, and which trees to cut. The best management recommendations will differ because timber stands differ. Most landowners often do not have the technical background to make cutting decisions. Loggers usually have an economic incentive to cut the most profitable trees - for them, but they usually do not have the landowner's financial interests in mind. So, it takes much experience to select the best cutting strategy.

**Recommendation 4. Manage hardwood stands to increase growth rates and stand value.**

Forest owners often believe that forests can pretty much take care of themselves. This may be true to a degree: forests continue to grow year in and year out, even through market cycles. Trees get larger, some die, and new seedlings start without any real assistance. But, left to grow without attention, few forests ever achieve their full economic potential. Most central hardwood forests can produce more timber and wildlife, and much can be achieved with carefully planned intermediate cuts, final harvests, and other improvements.

Many of the ways landowners can manage their hardwood stands involve cutting, removing, or killing trees and other vegetation. Cutting undesirable trees is necessary to focus growth on crop trees. In addition, new sprouts or seedlings needed to regenerate new stands are encouraged by removing unwanted overstory competition. In partial cuts, only carefully selected trees are removed. Complete harvesting is essential to start a new vigorous forest of the high-value central hardwood species that require full sunlight for establishment and growth. Complete harvesting is often needed to rehabilitate stands that have been neglected or abused by destructive harvesting in the past.

The relationship between regeneration and harvesting merits special attention. Harvested trees and trees with little value must be replaced with desirable species suited to the site to improve productivity. Careful planning for regeneration is needed <u>before</u> cutting. How much canopy to remove, which trees to cut, when to harvest, and many other factors can make the difference between successful regeneration and poor stocking or low-value trees. Regeneration is so critical to profitable management that it must be considered a primary goal of harvesting.

Mixed hardwood stands may need some attention every 5 to 15 years. In some cases, noncommercial treatments such as cleaning to kill or remove undesirable trees may be necessary. Each management action can be thought of as a mid-course correction. Missing needed treatments may be costly because the resulting future stand may be far less valuable. Missing treatments can delay stand development, postpone harvests of mature timber, and allow undesirable trees to prosper.

Noncommercial thinnings or cleanings should improve the stand enough to justify their cost. Some benefits may be from increased future timber values, but other non-timber benefits are certainly valuable too and should be considered when planning management treatments. Recently cut timber stands may appear unsightly, but they regain their appearance quickly if the harvesting operation was well planned.

Active stand management may suggest a goal of timber production to some, but even many treatments to enhance wildlife habitat involve some form of harvests. Brush or slash may be pushed into piles to provide wildlife shelter. Small openings are especially valuable to some species for the type of food and forage produced in them. Such openings can serve as places to concentrate and harvest game. Openings can also be planted to preferred wildlife food crops to favor particular species. Although many landowners believe timber cutting reduces wildlife, many species use clearcuts or young forests extensively for food or breeding.

**Recommendation 5. Manage wildlife values for additional sources of income.**

Many landowners seek non-timber benefits from their hardwood forests, particularly wildlife and recreation. Most activities to enhance wildlife involve vegetation management such as planting game foods, cutting immature trees, and harvesting mature trees. Final harvests and improvement cuts can be planned to improve wildlife habitat as well. Timber and wildlife are often viewed as conflicting goals, but many stands can be managed to produce more of both.

Hunting leases are becoming more common throughout the United States, and this source of income should not be overlooked as a way to

supplement earnings. The market for hunting leases is growing rapidly, but it is not well organized at this time. Annual fees paid for prime hunting locations are often set at the landowner's cost for property taxes. In time, prices may rise and be set through competition. Many hunters prefer leased land because it is less crowded, is generally safer, and may offer greater chances of success that other land. Hunting leases usually require larger tracts, but several landowners can combine their forest holdings to offer a single lease to hunting clubs or selected groups. The added income can be used in part to enhance wildlife populations, eventually leading to higher lease rates for the improved habitat.

Hunting leases are emerging as a growing competitive market in many areas, but they may not be for every landowner. Landowners wanting to lease their property should get professional forestry advice and have a clear contract to limit their liability.

**Recommendation 6. Promptly salvage damaged timber to minimize losses, recover value, and improve stands.**

Hardwood forests can be damaged by many natural hazards including fire, storms, ice, drought, insects, and diseases. Logging damage to residual trees is also a common cause of financial loss. Hardwood stands need adequate protection and treatments to reduce losses when they are damaged. Forest stands affected by natural events are not usually destroyed completely. Rather, growth and quality are reduced when individual trees or groups are killed, broken, scarred, attacked, or infected. Owners lose the value in destroyed trees and in future growth and quality from damaged trees.

Some management decision must be made when such damaging events occur. Many landowners do nothing to recover salvageable timber or to limit future financial losses. The basic management choices are to (1) leave the stand alone, (2) salvage and continue to grow the stand, or (3) harvest all trees, start over, and regenerate. Many factors such as landowner objectives, stand value and extent of damage, local markets, and the stand's ability to recover from damage, influence the decision after a loss. From a purely financial perspective, the best choice is to select the option that offers the greatest future value and to ignore the past or sunk costs that can never be recovered.

Salvage should always be considered after a loss. Sometimes not enough timber volume is affected to allow a commercial harvest. In this case, improvement cutting can be combined with salvage of damaged timber to enhance future stand values. Damaged trees that are left to grow take up growing space but may never increase in value. Unless harvested quickly, damaged timber may be attacked by insects and diseases that render it useless. If the damage is extensive and markets are strong, the best action may be to harvest all or most of the stand and regenerate. Even if no market is available for damaged timber, removal of the damaged trees for firewood may be needed to maintain a healthy and productive stand.

There are important income tax considerations when timber is damaged. Timber damage can qualify as a casualty loss for income tax purposes if the damage is sudden and unexpected. Fires; extreme weather such as tornados, ice, floods or drought; and some insects may qualify. The amount of casualty loss for income tax purposes is limited to approximately the initial timber investment, not the market value at the time of the loss. Unfortunately, this value is usually very low or zero for most natural hardwood stands. If this is the case, even completely destroyed stands may not qualify for any tax deduction under current tax provisions.

**Recommendation 7. Design timber harvests to favor prompt regeneration of desirable species.**

Many landowners cut timber but fail to adequately regenerate their land following harvest. They never plan for the next forest and count on nature to provide a new stand from whatever is left. A new forest will eventually regrow on most cut-over land, but the new stand will usually be far less valuable and productive than could be achieved otherwise. Usually, the next stand grows from the least desirable unmerchantable trees left on the site rather than from the best genetic stock. Failing to regenerate timberland after harvest will reduce long-term productivity.

Landowners sacrifice much future income when they allow harvested acres to remain idle and unmanaged. The goal of regeneration is to get enough new trees of the most desirable species. A large share of potential profits depends on regeneration success. Harvested hardwood stands are usually regenerated from seed or sprouts or from seedlings already in the stand. Shelterwood harvesting may be needed in several stages to establish an advance crop of seedlings before the complete overstory is cut. This is particularly true for oak. Desirable species can be encouraged by controlling how much canopy is removed and which trees are cut, by preparing the seedbed, and by killing unwanted trees before or after the harvest.

The best regeneration results are achieved by planning for the next stand before any trees are cut. Cost savings, more effective control of stocking and species mixtures, and more complete utilization can be achieved by coordinating harvesting and regeneration. Rather than leaving regeneration to chance, experienced foresters can guide each stand to produce a more productive new forest.

Hardwood regeneration is not always costly in dollar terms, but it does take time and special

skill to get the desired results. Many things can inhibit successful regeneration such as competing understory vegetation, inadequate nutrients, light, or moisture, and insufficient site preparation. Stand improvement treatments may be needed before or after harvest, and these can add to the cost significantly. The least costly method of achieving adequate regeneration is to be sure harvesting creates the right conditions for tree growth. The benefit of successful regeneration is a much improved stand and eventually greater profits.

Many landowners believe small partial harvests every decade or two is the best method. But this method is not a good way to produce most of the high-value central hardwood species. These species must have full sunlight for establishment and development. Consequently, complete overstory removal is essential if species such as oak, ash, walnut, and cherry are to achieve their best potential.

Harvested stands can be planted, but this is a difficult and costly option. Planting may be the only way to establish desirable species not present because of past history and to introduce genetically superior trees. Planting hardwoods such as oak, ash, or walnut may require intensive site preparation to reduce understory competition. The costs of planting and tending hardwood plantations are high and the time until harvest is long. Therefore, these long-term forestry investments should only be considered on the very best sites.

**Recommendation 8. Seek multiple buyers for timber and sell it by competitive bid if possible.**

Timber is often sold directly by landowners without the benefit of competition or a timber appraisal. Also, landowners are often poorly informed about local timber markets, the volume of their trees, or the value of their stand. Many landowners lose a large share of their profits because they don't know much about timber markets and can't judge the fair market value of their timber. Then they sell below market value to buyers who do know the true value of their timber.

Timber sales offered competitively with sealed bids are a more consistent way to be sure that a timber sale earns the highest market price. Negotiated sales are sometimes necessary to salvage timber quickly or for other reasons. Even if this is needed, landowners should have a knowledgeable forester do the negotiating.

Another problem occurs frequently when timber is sold and harvested without professional forestry assistance. When given a free hand, loggers will cut what they can sell profitably and leave the unmerchantable trees. This can greatly increase the cost of regenerating the next stand, adversely affect future productivity, and mean less money for the landowner.

**Recommendation 9. Use a harvesting contract when cutting timber to protect productivity and achieve management objectives.**

The trees to be harvested and left must be carefully selected and controlled. Harvesting contracts clearly specify the trees to be cut, the type of harvesting allowed, the method of payment, and the time allowed for harvest. They are legal instruments to protect the landowner and convey title to the timber to be cut. Contracts may include provisions to protect forest roads and streams, to prevent or require cutting of certain trees, to cover slash disposal, and to permit or limit other activities associated with harvesting. Contracts usually outline the consequences of not meeting the contract provisions. In some cases, a performance bond or advance payment is required from the logger before cutting begins. Most reputable loggers are accustomed to operating with contracts, but many timber sales are not covered by one. When loggers can do whatever they want, landowners usually lose.

Sample harvesting contracts are available from many consulting foresters, public forestry offices, extension forestry groups, university forestry departments, and county cooperative extension offices. Model contracts must be modified to reflect each landowner's particular situation.

**Recommendation 10. Use cost-sharing incentive programs when possible to reduce direct costs and increase productivity.**

Forest management practices can be costly and returns are far in the future. Consequently, cost-sharing programs help non-industrial private landowners reduce economic risks. Most programs contribute part of the cost for selected treatments to improve the productivity of private forests. Use these programs when they can help accomplish forest management goals and reduce costs.

The Conservation Reserve Program (CRP) provides cost-share payments to establish trees on highly erodible croplands and fields, subject to scour erosion, and makes additional annual payments for 10 years. This is not long enough to grow a timber crop, but the cost savings create an excellent earnings potential. The CRP requires enrolled land to be removed from agricultural production for at least 10 years.

The Forestry Incentive Program (FIP) will pay landowners to establish trees or improve stands for timber. The Agricultural Conservation Program (ACP) pays for certain conservation practices, including some to improve woodlands. These programs are administered by the Agricultural Stabilization and Conservation Service in cooperation with the State forestry agencies. Some States also have special cost-sharing

programs to help pay for improvements to private forests. These public programs relieve at least some of the financial burdens of improving forests.

**Recommendation 11. Carefully plan for the tax consequences of timberland income and assets.**

Income, estate, and property taxes are complex and costly. Some landowners pay more taxes than necessary because they don't understand the tax regulations and don't plan their management activities to take advantage of provisions favorable to forestry.

The Tax Reform Act of 1986 greatly changed Federal income tax regulations for forestry. The most significant change was the elimination of preferential tax rates for capital gains. As a result, timber income is now taxed at a higher rate than before the law took effect.

The deductibility of certain forest management expenses was also changed by the 1986 law. As a result, landowners may not be able to deduct all expenses unless they meet certain criteria for active management of their land. The rules on deductions are complicated, but landowners who actively manage their land generally receive the most favorable deductions for management expenses.

The favorable reforestation tax credit and amortization provisions remain in effect. These provisions allow landowners to quickly recover their reforestation costs, up to $10,000 per year.

Estate taxes affect timberland passed on to heirs. Many landowners have large and valuable timberland holdings that cannot be easily converted to the cash needed for estate taxes. In some cases, heirs have had to liquidate timber during weak market periods or when stands were not ready for harvest to settle estates. Landowner's objectives are not usually well served when they must cut timber, sell land, or divide forest holdings to pay estate taxes.

The need for unplanned and forced harvests can be reduced and timberland ownership can be preserved by effective estate planning. Many methods are available to reduce estate tax impacts and preserve timberlands and other assets for heirs. Get qualified tax and legal assistance to protect heirs from the unforeseen consequences of estate taxes on timberland values.

Property taxes, yield taxes, and severance taxes also affect timberland management by imposing costs each year and possibly at harvest. In some States, special provisions are available for reduced property taxes. To qualify, landowners may be required to follow an approved management plan or to allow public use of their land for hunting and recreation. Enrolling land under these special laws can reduce property taxes significantly. Check with your State forestry office or a qualified forester to determine if timberland can qualify for these provisions.

The Federal and State tax laws are complex and difficult to interpret for each landowner's situation. The best recommendation is to seek the advice of qualified forestry tax experts to help select the most advantageous management actions. Tax workshops may be available to help timber owners understand the effects of taxes on profits.

**Recommendation 12. Compare the financial performance of forest management activities with other investment options.**

Many landowners believe that active forest management is not profitable, but this is not the general case. Many factors affect the income potential of managed forests. Some timberland investments pay competitive returns, especially for well-stocked managed timber stands on highly productive sites in strong market areas.

Forestry investments may be considered in several ways. Investments made now increase the future quantity and/or quality of timber or other forest outputs. With hardwood forests, the investment cost is often not a direct outlay. It is revenue lost from not cutting a stand and holding it to grow another year. Forest owners should reasonably expect that the benefits in a year will be equal to the current stand value plus at least as much as could be earned on that value in a bank (or some other investment). With investments, the benefits are always delayed and received some time in the future.

Achieving a profitable forest requires an investment perspective when making timber management decisions. Money spent to improve tree growth or earnings can't be spent on other things or invested elsewhere. So, timber investments must be able to earn a competitive return. This means that treatments that can't earn an acceptable profit should not be done, if profitability is a goal.

The concept of financial maturity is an important one, especially for hardwood forests. Trees should be harvested when they reach financial maturity, when the rate of value growth falls below the interest rate that could be earned in another investment. Foresters determine this by measuring recent growth rings and comparing the value increment with the total value of the tree. If trees are held to grow too long, then their rate of earnings falls below competitive rates. If they are cut too soon, then much potential value growth is sacrificed. Usually financial maturity is specified as "critical diameters" for a particular situation. The diameter of financially mature trees depends greatly on the species, local markets, site quality, and amount of competing timber, so no single number can suffice. Invariably, this economic diameter is larger than the minimum diameter or size of trees acceptable to loggers.

Forest landowners should especially consider intermediate stand treatments to improve the growth of pole timber or small sawtimber crop trees. Improvement and cleaning cuts to remove or kill competing low-quality trees will enhance the growth and vigor of remaining crop trees. Because these crop trees may already be close to harvest, the investment period is relatively short. The faster growth rate on the select trees will also allow an earlier harvest. If conditions are right, this low-cost investment can pay handsome returns. Timber stand improvement treatments are especially profitable when stands are overstocked and growth has slowed or where the best trees are being crowded out. Unfortunately, many landowners believe that spending money to improve their stands is wasteful, but in many cases they are wrong.

Of course, investment returns play only a small role in deciding how to manage hardwood stands. Landowners may want less income and more intangible forest benefits, but they often unknowingly lose out by not managing their stands effectively. In many cases, landowners can have more timber, more income, and more non-timber benefits simultaneously by actively managing their hardwood forest. They do not always need to embrace timber production as a primary goal.

## SUMMARY

Owners of central hardwood forests want to get the most from their land and generate income without paying too much and without sacrificing the amenities or non-timber benefits. Twelve recommendations are offered to help these owners achieve greater profits in conjunction with their other goals. Profitable management of hardwood forests requires careful selection of treatments and planning of harvests.

The first recommendation points to the need for professional forestry assistance to help make the best management choices in diverse and complex hardwood stands.

Recommendation number 2 is to concentrate timber management efforts on the most productive sites where tree growth rates are the highest. This is where the greatest return on investment can be made.

The third recommendation recognizes that the greatest values in hardwood stands are found in the best quality trees of preferred species. Actions to develop, protect, and enhance the quality of the most valuable trees are essential.

The fourth recommendation points out that landowners must not overlook important opportunities to improve their forests. The timing of harvests and noncommercial treatments is critical.

The fifth recommendation recognizes the potential for income from wildlife in hardwood stands. Profitable management can easily include treatments to enhance wildlife, and hunting leases are becoming an important source of income.

The need to promptly salvage damaged timber and make the best choices after a stand has been damaged is the sixth recommendation. Damaged hardwood forests need care to keep them highly productive.

The seventh recommendation calls for careful planning for regeneration in conjunction with harvests. Regeneration is critical to profits and always more successful if the right conditions are created when trees are cut.

The message in the eighth recommendation is that timber should be sold by competitive bid to get the highest price. Professional forestry assistance is especially important to help landowners realize the fair market value of their timber.

Hardwood trees are especially vulnerable to logging operations. So, the ninth recommendation calls for harvesting contracts to reduce the risks when cutting timber.

Management of hardwood stands can be costly. The 10th recommendation is to use available cost-sharing programs for financial assistance when possible to keep cash outlays to a minimum.

Some of the important costs of forest management operations are income, property, and estate taxes. Taxation of forestry operations is complicated and requires special advice. The 11th recommendation is to carefully plan for the special tax consequences of owning forestland.

Finally, the 12th recommendation is to consider the financial returns of specific forestry actions and compare them with other investment options. Too often landowners have little information on the return they can expect from managing their forest. Perhaps their choices would be different if they knew the payoffs.

Money doesn't grow on trees, but many landowners can profit by carefully managing their hardwood timberlands. Landowners who choose not to actively manage their forests may forego benefits and eventually reduce the attractiveness and productivity of their stands. In some cases, landowners may not realize how their forests can be improved or how some investments can add profits and improve other benefits. These recommendations are offered to help landowners better understand their opportunities.

# SOME PERSPECTIVES ON OAK DECLINE IN THE 80'S[1]

Kenneth J. Kessler, Jr.[2]

Abstract.--A review of the past 80 years of oak decline revealed major episodes of oak decline in the 1920's and 1930's, and in the 1950's and 1960's. Most oak decline research of the past was observational in nature. Suggestions for future research include (1) the use of long-term permanent study plots,(2) controlled stress factor experiments, (3) comparative studies among oak species, (4) better quantification of stress factors for use in modeling and predicting declines,and (5) site modification and management studies to ameliorate decline.

## INTRODUCTION

The purpose of this paper is to review the historical record of oak decline episodes in the past 80 years and then suggest areas where additional research is needed and where possible new experimental approaches might be appropriate. In this analysis, oaks of the Midland Hardwood Forest and the Appalachian Forest (Barrett 1980) are emphasized. Decline diseases of oak have periodically been noted in the eastern deciduous forest--particularly affecting members of the red oak group, subgenus Erythrobalanus (e.g., black, scarlet, pin, and red oak). The extensive literature on these past declines indicates that oak decline has been a recurring phenomenon during the 20th century in the eastern United States.

## OAK DECLINE DEFINED

Oak declines are complex plant diseases that develop when trees altered (predisposed) by abiotic and/or biotic stresses are invaded and sometimes killed by opportunistic organisms of secondary action. Predisposing and secondary stress agents that may be involved in oak decline are:

Predisposing Stresses

| Abiotic | Biotic |
|---|---|
| Drought | Defoliation |
| Soil flooding | -insects (e.g. gypsy moth) |
| Winter injury | -diseases (e.g. oak anthracnose) |
| Late spring frosts | |
| Highway deicing salt | |
| Air pollutants | |

Secondary Stresses

Ultimate Mortality-causing Agents

Bark borers (Two-lined chestnut borer)
Root borers (Prionus species)
Root pathogens (Armillaria)
Bark pathogens (Hypoxylon)

Some characteristics of declining trees may be:

1. Reduced growth.
   a. Shoot growth elongation.
   b. Diameter growth.
   c. Smaller leaf size.
2. Dieback.
   a. Twigs and branches.
   b. Roots.
3. Sprouts arising from latent or adventitious buds.
4. Chlorotic foliage.
5. Premature fall coloration.
6. Reduced stored food reserves.
7. Reduced resistance to attacks by opportunistic pathogens and insects.
8. Degeneration of mycorrhizae.

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## PAST INVESTIGATIONS OF DECLINE

### Earliest Reports

Jensen (1901) described what appears to be a typical pattern of oak decline that occurred in southeastern Wisconsin around the turn of the century. Scarlet, red, and white oaks were affected, bur oak was not. The decline was thought to have been initiated by a period of unusually severe drought in 1893-1895. The climax of the decline followed the severe winter of 1898-1899--a winter with abnormally low temperatures and no snowfall. As a consequence of the lack of snow cover, the ground froze to great depths and did not thaw until the end of April. Greatest oak mortality occurred on "hard pan" soils.

A few years later Chapman (1915) reported mortality of scarlet, red, white, and bur oaks in southeastern Minnesota. In Minnesota trees weakened by factors such as drought and soil compaction from excessive pasturage were attacked by the Armillaria root rot fungus, Armillaria mellea, and the two-lined chestnut borer, Agrilus bilineatus. Death of trees was attributed to the attack of the root rot fungus and/or the stem invading beetle larvae.

About the same time in New York State, mortality of white oak and chestnut in an area where the chestnut blight organism was not present was attributed to A. mellea attack (Long 1914). Old stumps were thought to serve as a "breeding ground" for the mycelium of the fungus before invasion of living trees.

According to Baker (1941) the gypsy moth (Porthetria dispar), accidentally introduced into the Northeastern States in 1869, had become a serious pest of oaks in that region by 1890. Oak mortality associated with repeated defoliations by the insect peaked in 1912-1915 after a period of severe drought. At the same time, an outbreak of the two-lined chestnut borer hastened the death of oak trees weakened by defoliation and drought. Armillaria mellea was also noted as a ubiquitous root rot fungus that attacked and hastened the death of low vigor trees. Baker further established that single, complete defoliations by the gypsy moth rarely killed trees, but did greatly reduce diameter growth the same year of the defoliation.

An early attribution of tree injury to the effects of acid deposition was presented by Galloway and Woods in 1896. They stated that "In the vicinity of manufacturing establishments and often in cities and villages where large quantities of bituminous coal are used, vegetation, especially trees and other woody plants are frequently injured by the fumes which are thrown off into the atmosphere." They further concluded that the chief injury was due to sulphurous and hydrochloric acids. Symptoms of pollution damage they described included reddish brown spots and marginal necrosis of leaves and cumulative dieback of tree crowns year after year.

### Oak Decline in the 1920's and 1930's

Drought was a primary factor in several episodes of oak decline during the 1920's and 1930's. In the southern Appalachians a drought around 1925 caused extensive mortality of black oak (Hursh and Haasis 1931). Red and scarlet oak were also affected but to a lesser degree. Chestnut oak was least affected by the drought. Armillaria root rot and the chestnut borer were thought to be secondary factors that contributed to the impact of the drought.

Balch (1927) noted that the 1920's oak mortality in the southern Appalachians appeared to peak around 1927 and attributed it largely to drought in 1925 and late frosts at the end of April 1927. Most of the dying oaks were mature dominant trees that had been growing poorly for the previous decade. Dying trees often had extensive trunk rot and carpenter worm infestations. Their roots frequently harbored Armillaria mycelial fans and Prionid root borer larvae. All affected trees showed varying degrees of infestation by Agrilus bilineatus larvae.

In Pennsylvania an extended drought round 1930 caused extensive losses of scarlet and black oak (McIntyre and Schnur 1931). Chestnut and white oaks were little affected. The drought produced changes in species composition of all oak types on severely affected areas except for the chestnut oak type.

Parr (1937, 1940) described a dieback-decline of chestnut oak in Connecticut during 1933-1937 caused by heavy infestations of the pit-making oak scale, Astrolecanium variolosum. Chestnut oak is the preferred host for this scale insect. Trees on poor sites were more seriously affected by scale infestation than those on better sites. White oak was occasionally infested when closely associated with chestnut oak. Black and scarlet oak were not attacked by this scale even when growing near chestnut oak.

Knull (1931) was one of the first investigators to observe that oak defoliations caused by complexes of several species of defoliators could lead to tree decline and mortality. In Pennsylvania he described a synergistic complex where defoliation by the elm spanworm, Ennomos subsignarius, and the fruit tree leaf roller, Archips argyrospila, weakened trees' defenses to attack by the two-lined chestnut borer.

### Oak Decline in the 1950's and 1960's

In the 1950's many red oaks, particularly scarlet oaks, died in Pennsylvania (Fergus and Ibberson 1956, Hadley 1956), West Virginia (Gillespie 1956, Tryon and True 1958), and Virginia (Skelly 1974, Staley 1965). Fergus and Ibberson (1956) suggested that, although drought may have been involved in some areas, oak mortality was occurring on all types of sites and environmental conditions. In West Virginia Gillespie (1956) found that many dead

oaks had declining growth for 6-8 years before dying. Before a tree died, leaves in the upper crown often suddenly turned brown and wilted during late July-early August. In subsequent years, a gradual dying back of branches occurred in the bottom two-thirds of the crown of such trees. Tryon and True (1958) observed that the root systems of declining trees were the last parts of the trees to die.

Staley (1962, 1965) provides the best and most extensive coverage of the oak decline of this period. He found that the principal factors involved in the decline were leaf roller defoliation, root rot, Agrilus borer attack, late spring frost, drought, and unfavorable soils. Drought, frost, and root rot were considered contributors to the decline but not the primary initiating agents. He also concluded that initial symptoms of decline indicated diminished availability of carbohydrates for growth and that final symptoms leading to mortality reflected extreme moisture stress.

In Canada ice damage to red oak during the winter of 1959-1960 reduced tree vigor and predisposed trees to Armillaria root rot infections. In addition the twig colonizing fungi, Pseudovalsa longipes and Diatrypella quercina, were associated with crown dieback in the reduced vigor trees (Dance and Lynn 1963).

Nichols (1968) maintained case histories of 70 stands experiencing oak mortality in Pennsylvania. Mortality in all the 70 oak areas was always preceded by either heavy insect defoliation or severe frost damage. Generally two consecutive years of 60 to 100 percent spring defoliation were required to kill the trees. Nearly all dying and recently killed trees were infested by the two-lined chestnut borer.

Drought was not judged to be a major cause of mortality as evidenced by data from the 70 areas collected during the severe drought years 1962-1966. The effect of drought was judged to be roughly equal to that of a moderate defoliation. Yearly growth losses in terms of annual ring growth following dry years never exceeded 30 percent of normal growth.

## Oak Decline in the 1970's and 1980's

Dunbar and Stephens (1975) studied mortality patterns of oaks severely defoliated by the gypsy moth and elm spanworm in Connecticut. Mortality ranging from 18 to 79 percent was attributed mainly to stem and branch girdling of the weakened trees by the two-lined chestnut borer. All dying and recently dead trees contained borer larvae. In contrast, mycelial fans of the Armillaria root rot fungus were found under the bark of only 31 percent of the recently dead trees and under none of the dying trees.

Wargo (1977) attributed a more important role to Armillaria root rot in killing oaks severely defoliated by the gypsy moth. By using a tractor-mounted front-end loader, Wargo excavated root systems to examine the extent of root rotting. The roots of most recently dead or dying trees were found to be extensively colonized by the Armillaria root rot fungus, even though in many instances the fungus was not visible at the root collar. The results suggested that both Armillaria root rot and girdling by Agrilus larvae were involved in tree mortality and that trees died because water and food relations were drastically disrupted in the stem by the borer and in the roots by the fungus.

A decline of red oak in western North Carolina on upper slopes in 1979 was thought to be initiated by lower than normal February temperatures in 1963 and then aggravated by dry summers starting in 1968 and worsening in 1973-1978 (Tainter et al. 1984). After 1979 those trees surviving experienced little subsequent decline.

In the Missouri Ozarks, scarlet oak and black oak experienced serious mortality that began around 1978 and extended into the early 1980's (Law and Gott 1987). Scarlet oak stands more then 60 years old were most affected. Weather factors that may have played a role in the mortality were (1) prolonged high temperatures during the summer of 1980, (2) two severe winters of 1976-1977 and 1978-1979, and (3) below normal rainfall during 1976, 1978, and 1980. Secondary organisms contributing to the decline appeared to be the two-lined chestnut borer and the stem and branch colonizing fungus, Hypoxylon atropunctatum.

Oak mortality-decline was also a problem in Kentucky and surrounding States in the 1980's (Stringer et al. 1987). Chief oaks affected were black, scarlet, and red oak. Principal factors responsible for the decline appeared to be drought, intra-stand competition, and Agrilus stem girdling. Dissection of root systems of declining and dying oaks revealed no indication of Armillaria root rot infection.

Although oak mortality and decline have occurred in both North American and European regions where air pollutant concentrations, including acid deposition, are high, field evidence of adverse effects on growth of oaks remains inconclusive (Smith 1987). McClenahan and Dochinger (1985) studied whether air pollutants had an effect on stem growth of white oak in a highly industrialized portion of the Ohio River Valley in southern Ohio. Their results suggested that nonclimatic factors, presumably pollutants, had caused annual growth reductions in the industrialized portion of the Ohio River Valley, particularly after 1930. Detrimental effects of ambient ozone concentrations on net photosynthetic rates (output growth reductions) have been demonstrated for red oak (Reich et al. 1986) and black oak (Carlson 1979). Reich et al. (1986) found that red oak seedlings were relatively insensitive to acidic rain over a single growing season, although acidic rain did cause decreases in percent and numbers of short roots infected by mycorrhizal fungi (Reich et al. 1985).

Phipps and Whiton (1988) studied long-term growth trends in 60 white oak stands located throughout the white oak range. A permanent, non-reversed growth decline apparently as a consequence of a growth rate change in the mid 1950's was noted in the white oaks in two-thirds of the stands. The event in the 1950's that initiated the growth decline did not appear to be related to either climate or pollution.

Mueller-Dombois et al. (1983) compared oak decline with other North American decline diseases. The other declines were maple decline, birch dieback, pole blight of western white pine, and little leaf disease of southern pines. In all these declines, trees typically died in groups rather than singly. This spatial pattern of mortality was thought to be due to a stand dieback mechanism that involved (1) cohort senescence as a predisposing cause, (2) a sudden adverse perturbation of the stand as a secondary cause but serving as a synchronizing cause, and (3) biotic agents as tertiary causes but contributing to dieback and mortality. Cohort senescence was defined as uniform loss of vigor of a canopy cohort due to aging and gradually increasing environmental stress. Cohort senescence was viewed as a normal phenomenon of population dynamics rather than as a disease.

## RESEARCH NEEDED AND SOME POSSIBLE EXPERIMENTAL APPROACHES

1. Long-term permanent study plots. Most oak decline studies of the past have involved studies within single States. Regionwide studies to monitor and ascertain the decline status of north central oak forests are needed, particularly to establish if decline is primarily a local problem or a regionwide one. Permanent study plots regularly remeasured and observed can be used to establish the relative importance and interaction of various decline causal agents.

2. Controlled stress factor experiments. Experiments where several levels of suspected stress factors are applied to oak decline candidate trees are rare. Gradwell (1974) hand defoliated oaks to simulate insect defoliations occurring at different times of the year. Air pollutant treatments at several concentrations have been applied to young oaks under greenhouse and growth chamber conditions (Carlson 1979, Reich et al. 1985, 1986).

Critical experiments where concentrations of root and stem borer infestations are varied or intensity of Armillaria root infection is controlled are desirable to establish the importance of such secondary stress agents in the decline syndrome. Application of moisture stress regimes to large oaks in the field could be patterned after studies by Copeland (1955) on drought effects on shortleaf pine and by Skilling (1964) on sugar maple blight.

3. Comparative studies among oak species. Most cases of oak decline have involved selected oak species. Often only members of the red oak group are chiefly involved. White oaks and hickories occupying the same sites are generally affected to a much lesser degree. Comparative studies of several species occupying the same decline sites could involve analyzing their site requirements for major and minor nutrients and moisture throughout their phenological development. Survival adaptations that involved drought and cold tolerance, crown type, rooting pattern, root-shoot ratio, growth rate and time of growth could be usefully compared. Finally, much needs to be learned about allelopathic relationships among the trees, shrubs, and herbaceous vegetation of oak stands.

4. Quantification of stress factors, modeling, and predicting decline. While most of the abiotic stress factors--moisture stress, cold injury, pollutant concentrations, heat stress, etc.--can be quantified providing resources are available for instrumentation and data gathering, the biotic factors, particularly the diseases, are harder to quantify. Few experiments have been conducted with forest tree declines where disease levels have been regulated or actually increased by artificial manipulation. To develop good oak decline models, all the suspected stress agents must be quantified particularly to study how different levels of several stress agents interact. The possible interaction of relatively low levels of several stress agents that singly would have little effect on tree growth would be an early candidate for modeling. The historical recurrence of oak decline plus the added effect of possible changes in global warming suggests that new waves of oak decline will occur in the future. Predictive models that anticipate oak decline are needed by forest managers and planners. Finally, generalized models are needed that can take conclusions from local areas that have been intensively studied and apply them to large forest units.

5. Site modification and management. Detailed knowledge of the requirements to initiate a decline may provide information as to how sites could be manipulated or better managed to avoid decline. Some items for experimentation are species composition, understory changes, and fertilization including liming some acid soils.

Many of the sites where oak decline is most severe are former chestnut sites. Perhaps the oaks that have colonized the chestnut niche are not particularly suited to these sites. The time may be approaching (or is here) where the technology is available to transfer a chestnut blight resistant gene from resistant Asiatic chestnut or possibly one of the oaks to American chestnut. A national commitment to return the American chestnut to its former preeminence would probably have strong appeal to a diverse segment of the American population.

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LANDSCAPE ECOLOGY: AN ECLECTIC SCIENCE FOR THE TIMES

Thomas R. Crow[1]

Abstract.--The primary focus in landscape ecology is on spatial (and temporal) patterns and how this heterogeneity affects biotic and abiotic interactions. These interactions vary depending on spatial scale and so problems of scale are an integral part of landscape studies. Principles of landscape ecology are beginning to emerge that should help provide the theoretical and empirical basis for a variety of applied sciences -- including regional planning and natural resource management.

## INTRODUCTION

A field of scientific inquiry entitled "landscape ecology" has emerged in recent years that has significance for a variety of applied sciences including regional planning and natural resource management. Still in its infancy, landscape ecology lacks the rigor and definition of a well-established scientific discipline; however, as it matures, its concepts and paradigms will provide a useful theoretical and empirical basis for many resource management decisions.

Landscape ecology can best be considered as the intersection of numerous related disciplines, including ecology, geography, forestry, landscape design, wildlife biology, genetics, and sociology (Risser et al. 1983, Naveh and Lieberman 1984, Forman and Godron 1986, Risser 1987, Urban et al. 1987). It is composed of elements drawn from many sources, an eclectic science, as opposed to being a distinct discipline or simply a branch of ecology. More specifically, landscape ecology focuses primarily on the relationships between spatial and temporal patterns and ecological processes. Landscape patterns have often been described as dynamic mosaics, changing in time and space, and these patterns reflect both human impacts as well as physical features such as climate, physiography, and soils. The redistribution of materials, energy, and organisms among landscape elements in both time and space is an essential feature of landscape ecology.

## CHARACTERISTICS OF LANDSCAPES

Patches and corridors, two conspicuous features of the landscape, are critical structural and functional units. The characteristics of these units -- size, shape, width, connectivity -- can be easily quantified (Milne 1988) and incorporated into studies of how the spatial arrangement of forests, bogs, roads, and cities, for example, affects the movement of insect pests, the spread of fire, the colonization of woodlots by animals, or the movement of people.

The grain size of a landscape mosaic is a measure of the average size or patchiness of the landscape. A landscape with fine grain has many small patches, compared with a landscape that has only a few large patches or course grain. Patch size is a major control over the physical and biological characteristics of an individual ecosystem. For many bird species, for example, patch size is an important habitat characteristic (table 1) that affects where a species will occur, and more importantly, whether a patch will support

Table 1.--Minimum size of woodlot that has at least a 50 percent chance of supporting a breeding population (from Temple 1988).

| Species | Woodlot Size |
|---|---|
| Hairy Woodpecker | 40 acres |
| Pileated Woodpecker | 240 acres |
| Acadian Flycatcher | 240 acres |
| Least Flycatcher | 160 acres |
| Tufted Titmouse | 80 acres |
| Blue-gray Gnatcatcher | 80 acres |
| Veery | 60 acres |
| Wood Thrush | 20 acres |
| Yellow-throated Vireo | 40 acres |
| Chestnut-sided Warbler | 160 acres |
| Cerulean Warbler | 200 acres |
| American Redstart | 240 acres |
| Ovenbird | 80 acres |
| Mourning Warbler | 160 acres |
| Hooded Warbler | 240 acres |
| Scarlet Tanager | 40 acres |

[1]Thomas R. Crow, Research Plant Ecologist, USDA-Forest Service, North Central Forest Experiment Station, Rhinelander, Wisc. 54501

a breeding population. The average woodlot size of only 47 acres in Temple's study area has significant implications for maintaining breeding populations of many species.

Many species require two or more patches to complete their life cycles. Amphibians, for example, need aquatic systems such as small ponds to complete their early larval stage, but spend much of their adult life in the uplands near the pond. The aquatic and terrestrial habitats need to be in close proximity. The use of different-aged stands by ruffed grouse (Bonasa umbellus) has been well documented (Gullion 1977). This species uses mature forests for feeding, intermediate-aged (pole size) stands for breeding, and young regenerating stands for brooding. Again, spatial proximity of these three stand conditions is an important requirement.

Corridors play at least four major functional roles. They act as conduits for the movement of materials and organisms, they act as filters or in some cases as barriers, they provide habitats for edge species, and they act as sources of biological and environmental effects upon adjacent areas (Forman 1986). Width and connectivity are two important structural attributes of corridors that, in turn, affect their functional characteristics. The availability of critical habitat within a patch can be enhanced by connecting similar patches with corridors. In Maryland, forest interior birds were able to maintain themselves in small woodlots when the woodlots were connected to much larger forested areas by corridors (MacClintock et al. 1977).

In the Midwest, fencerows serve as important travel corridors between forest fragments. Small mammals and birds common to the forest are more likely to traverse along the woody cover provided by fencerows than across open agricultural fields (Harris 1984). Influencing the travel patterns of seed-dispersing animal species affects the dispersal of plant species.

Streams, and the riparian zones associated with them, are good examples of corridors. A first-, second-, and third-order stream system forms a dendritic network that links components of the landscape. The various kinds of drainage densities and patterns present form a distinctive imprint that greatly affects the movement of water, nutrients, sediments, and animals within the watershed (Forman 1986). Major river corridors often serve as important flyways for migratory waterfowl and raptors. In areas greatly modified by humans, stream corridors are likely to be the only linkage among remnant patches of natural vegetation.

Edges have always been of interest to ecologists because of the concentration of ecological interactions that occur at the interface between two different ecosystems. It is not unusual to find species from both habitats at the edge along with species that are especially adapted to edge environments. Wildlife managers have always taken a special interest in edges because many important game species are edge species. The abundance of species brings an abundance of biological interactions. Animal activity, including herbivory and predation, is often greater along edges than in patch interiors (Wilcove 1985, Temple 1987). Increased predation along edges is thought to be related to increased prey densities and to the natural travel lanes created by abrupt changes in the vertical structure of vegetation (Reese and Ratti 1988).

In studying the development of an old growth beech-maple forest in Ohio, Whitney and Runkle (1981) concluded that position within the stand had greater impact on overstory composition than did the age of the stand. For example, while northern red oak (Quercus rubra) was abundant along the stand margins, it was virtually absent from the interior of the old growth forest. This conclusion is significant because of the conversion of midwestern forests to small, fragmented woodlots with high edge-to-area ratios.

## IMPORTANCE OF SCALE

Problems of scale are important to landscape ecology. The relations between spatial pattern, temporal change, and ecological processes depend largely on scale (Risser et al. 1983, Allen and Hoekstra 1987, Meentemeyer and Box 1987). Ecological processes differ in their effects and importance at different scales, and different species and groups of organisms operate at different scales. The appropriate scales at which to conduct landscape studies depends on the question being asked. Too often, however, the temporal or spatial scale used in a study is based more on the investigators' perceptions than on the organism(s) and ecological process(es) under consideration.

Including variation in both time and space can be challenging when considering landscape patterns. Many population models, for example, assume a homogeneous environment and a uniform distribution of individuals within that environment. Obviously, such simplicity severely restricts the utility of the models; more recently, ecologists have begun to consider population dynamics in heterogeneous environments (e.g., Wiens 1976, Levin 1976, Seagle and Shugart 1985, Lande 1987). In addition to linking time and space, landscape studies are likely to require shifting across several spatial and/or temporal scales. Because biological systems are hierarchical organizations, hierarchy theory offers some promising ideas for addressing complex biological questions at different scales (Allen and Starr 1982, Allen et al. 1984, Allen and Hoekstra 1987). The science of scale needs to develop in concert with landscape ecology, and much additional work remains in both areas. However, any general principles developed for landscapes will have to apply at all relevant spatial and temporal scales.

## APPLYING LANDSCAPE ECOLOGY TO MANAGEMENT - EXAMPLES

Landscape ecology, with its emphasis on spatial and temporal heterogeneity, provides a useful context for studying problems related to conserving biological diversity. There is increased recognition that human activities are inextricably linked to the accelerating loss of biological diversity (Myers 1979, Wilson 1985, 1988). Although direct impacts, such as the loss of species due to overexploitation, are a factor in some cases, indirect impacts such as habitat destruction are more important for most endangered species. Habitat destruction not only involves the loss of the original habitat, but even more insidious, it also increases the isolation of populations that required the original habitat. This process of fragmentation is common to growing societies where once large blocks of contiguous habitat are repeatedly divided into smaller and smaller blocks and separated by urban, agricultural, and industrial developments, and their accompanying infrastructures (e.g., roads, utility rights-of-way). Under these land-use patterns, opportunistic species that benefit from disturbance will prosper. These are often exotic "weed" species such as the introduced European starling (Sturnus vulgaris) or edge species such as the blue jay (Cyanocitta cristata) or raccoon (Procyon lotor) that adapt well to fragmented landscapes. In turn, area-sensitive species that require large tracts of habitat decline or even become locally extinct.

Changing landscape patterns between 1939 and 1974 on a 1,117 ha tract in southeastern Illinois resulted in the extirpation of prairie chickens (Tympanuchus pinnatus) from the area in 1969 and substantial declines in bobwhite (Colinus virginianus) and cottontail (Sylvilagus floridanus) populations (Vance 1976). Rapid intensification of cash-grain farming during that time eliminated grasslands and reduced woody cover along fencerows and in woodlots. Because prairie chickens require extensive grasslands, it is not surprising that the major factor limiting prairie chicken populations in Illinois and elsewhere is the lack of suitable grasslands for nesting. The loss of brushy fencerows was especially detrimental to bobwhite and cottontails (Vance 1976).

Pest management can be improved by understanding how landscape patterns affect pest movements and rates of infestations. In general, landscape homogeneity increases the spread of pests. Certainly this is true with agricultural systems, and examples can be also found in natural systems. Fire suppression in western conifers increases forest homogenization and forest maturity, and large stands of mature timber increase the frequency, intensity, and rate of spread of bark beetle infestations (Forman 1987).

Landscape patterns can significantly affect the potential for major forest disturbances. For example, forest cutting patterns and cutting intensities greatly affect susceptibility to windthrow. Franklin and Forman (1987) found the checkerboard cutting pattern commonly applied to Douglas fir forests in the Pacific Northwest greatly increased the frequency and severity of blowdown. Such a cutting pattern increases the contrast between adjacent units, increases the amount of exposed edges in the landscape, and isolates forest patches in cutover areas. Windthrow occurs most frequenly along exposed edges and at the corners of the residual blocks (Franklin and Forman 1987).

Road densities are a measure of landscape "mesh" and road densities have been shown to be an important landscape feature related to the distribution of the timber wolf (Canis lupus) in Wisconsin (Thiel 1985), Ontario (Jensen et al. 1986), and Minnesota (Mech et al. 1988). Wolves in the Great Lakes regions generally do not occur where densities of roads passable by 2-wheel-drive vehicles exceed 0.58 km/km$^2$. Roads themselves do not inhibit colonization by wolves; instead, human contact is the critical factor. Roads provide accessibility for humans, and humans, either deliberately or accidentally, kill wolves (Mech et al. 1988).

## METHODOLOGIES FOR LANDSCAPE ECOLOGY

Techniques and methods currently used in resource management and research can also be used in landscape ecology. Computers, mathematical models, geographic information systems, data-base management, remote sensing, and radiotracking are some of the practical tools available to landscape ecologists.

New methodologies are being applied as well. The development of fractual geometry has made it possible to quantify complex boundaries and patch shapes (Mandelbrot 1983, Milne 1988). Indices are also available for quantifying the degree of connectivity among landscape components (e.g., Pielou 1979).

## SUMMARY

Resource managers and planners increasingly recognize that informed management decisions cannot be made exclusively at the site or stand levels. The opportunities associated with a particular management unit are not only determined by the content of that unit, but also to a great extent by the context in which the unit exists. Regardless if the primary management object is producing timber, creating suitable habitats for common game species, protecting a watershed, or providing a wilderness experience, assessing these opportunities requires considerations that extend beyond the boundaries of the specific management unit. An increased emphasis on regional analyses requires a landscape perspective (Joyce et al. 1983, Evans 1986).

Although a landscape perspective is not unique to landscape ecology, (a landscape

perspective has been frequently embodied in many early writings in ecology, natural history, and wildlife biology, e.g., Leopold's Sand Country Almanac), the eclectic character of landscape ecology is unique and provides a potentially useful framework for many fundamental problems in resource management. While a theoretical base for landscape ecology is only beginning to emerge, the application of that theory is likely to soon follow. Indeed, incorporating spatial (and temporal) considerations into resource planning and management remains one of the greatest challenges facing our profession.

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INTENSIVE GROUP SELECTION SILVICULTURE IN CENTRAL HARDWOODS

AFTER 40 YEARS[1]

Leon S. Minckler[2]

Abstract.--In 1947 conferences of Forest Service research people from Federal, Regional, and Research Center units met in Southern Illinois to set up in 1948 a whole rotation study on the Kaskaskia Experimental Forest involving 38 commercial compartments. The chief objectives were to evaluate the success, ability for sustained silviculture, and the costs and returns for a full sawtimber rotation for different silviculture systems. The uneven-aged systems included intensive-group selection silviculture as a major component. This paper is confined to regeneration and stand growth on uneven-aged compartments with combined treatments of group selection, improvement cutting, and killing of cull trees. Active commercial cutting continued for 20 years after which the study was terminated in 1968. Photographs were taken in 1988 of the stands undisturbed since 1968. The treatments were successful in terms of regeneration in openings, stand quality, stocking, and net growth while maintaining a continuous and diversified forest cover.

## INTRODUCTION

In 1947 conferences of Forest Service people were held in Southern Illinois to decide on a research program for the Kaskaskia Experimental Forest located on the Shawnee National Forest. The conferees were composed of Washington high-level Forest Service research people and forest management research people from the Central States Forest Experiment Station and the Carbondale Research Center. An agreement was reached on the dominant study, hereinafter called the "Compartment Study" and a working plan was written and approved. This study was fully active for 20 years but terminated in 1968, about one-fourth of the work plan goal of one rotation. It is essential to note that numerous color slides were taken in March 1988 to show conditions at about half rotation in the absence of further cuttings or inventories since 1968.

## OBJECTIVES

Objectives of these commercial-type compartments (average 20 acres) were concerned with long-term silvicultural systems and variations of systems for both short and long-term values and to sustain a natural and healthy forest ecosystem. These objectives for uneven-aged silviculture included logging methods, various silvicultural systems, long and short cutting cycles, long and shorter rotations and intensive and extensive management. Even-aged silviculture included stand conversion from hardwoods to short leaf pine, two-cut shelterwood, and commercial clearcutting for sawtimber (no culls killed). Costs in physical units were kept for all operations. Two general sites were sampled, coves and northerly slopes vs. ridgetops and south slopes. During the 20 years (1948 - 1968) 106 cutting operations on 755 acres removed about 2 million bd. ft. of sawlogs.

This paper will cover only the uneven-aged intensive group selection silvicultural management method with data up to 20 years and slides

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[1]Paper presented at 7th Central Hardwood Conference at Southern Illinois University, Carbondale, Ill, March 5-8, 1989. Much of the oral presentation was slides taken in 1988.

[2]Leon S. Minckler retired in 1968 as Research Forester, U.S. Forest Service, Carbondale, Ill., after 33 years of service. He then taught for 9 years at Virginia Polytechnic Institute and SUNY College of Environmental Science and Forestry. Since 1977 he has been a forestry consultant living in Blacksburg, VA.

taken 40 years after start of management in 1948. This includes 21 compartments, 13 on coves and northerly slopes and 8 on ridges and south slopes. Because of ecological characteristics and past cutting history most stands on the Kaskaskia were uneven-aged at the start of management, as shown by actual inventory data.

## TREATMENTS

It is essential that the actual treatments as started in 1948 and continued thereafter be understood. At present it is common for foresters to use patch cutting and call it group selection. In this study the following classes of merchantable trees 11 inches d.b.h. and above were marked to cut over the whole management unit (compartment): financially mature but otherwise sound and desirable, high risk trees, and sound but low quality trees. Cull trees (unmerchantable now or in the future) were killed. All others, good growing stock, were left. Trees (poles) 5 to 10 inches d.b.h. which were potential good growing stock were left unless too dense. Others were killed. We had no markets for firewood or pulpwood. In this operation close attention was paid to find opportunities to create openings for new regeneration. As shown later, minimum size openings should be as wide as height of surrounding trees. Opening sizes will range up to one-half acre or even more on some poor areas. Openings are easy to create on previously unmanaged and often high graded forests. This is selection cutting based on tree and forest characteristics and not mechanical in nature. Financial maturity is based on some chosen percent value return and on site quality. Our mature trees ranged usually from 20 to 24 inches d.b.h. and good growing stock usually made up at least 50 percent of the basal area.

Control was by complete inventory giving volume and diameter distribution of the management unit as a whole. This could be done by sampling. Treatments were made in 5 to 6 year and 10 to 12 year cycles. Some compartments were cut three times. The ideal stand structure, volume, and tree quality was approached gradually and considerable flexibility was anticipated but the goal of a continuous forest was always maintained.

In intensive management time and money was spent to kill culls and do release and weeding as required. Thousands of cull trees were killed. Openings for regeneration were cleared of brushy competition if needed. For extensive management no culls were killed and no improvements made that involved costs. For example, the commercial clearcut compartments had a high residual of cull trees.

## NATURE OF THE ORIGINAL FORESTS AND EARLY RESPONSE TO MANAGEMENT

Early in the compartment study a complete inventory had been made on 22 compartments totaling 420 acres of unmanaged stands (Minckler and Roach, 1955). About 18 percent of the pole trees and 10 percent of the sawtimber-sized trees were culls. The average sawtimber volume per acre of merchantable trees was 4020 bd. ft. (International 1/4-inch rule), and composition by tree classes and size is shown in Table 1.

Table 1.--Volume per acre of unmanaged forests on first 22 compartments treated; Kaskaskia Exp. Forest

| Tree Class | Sawtimber 11-17 inches d.b.h. | Sawtimber 18 inches and larger | Totals |
|---|---|---|---|
| Growing-stock[1] | 1625 | 460 | 2085 |
| Mature and sound low quality | 695 | 695 | 1335 |
| Poor risk; over-mature and defective | 245 | 355 | 600 |
| Totals | 2565 | 1455 | 4020 |

[1]Number of trees per acre:
19 of 39 sawtimber trees were good growing stock; 46 of 94 pole trees were good growing stock.

The seven earliest cuts had a 600 bd. ft. per acre improvement cut and all culls killed. The average periodic annual net growth after cutting was 272 bd. ft. per acre (Minckler, 1955). Some of this was in-growth from the residual large poles (Minckler, 1957). Immediate and rapid increase in diameter growth of white oak occurred after release (Minckler, 1967) except for suppressed trees with poor crowns. Observation has shown that other species of oak poles still vigorous and with good crowns also responded to release.

Another early example of response to intensive management and group selection in two cuts (1952 and 1959) was the 21-acre "poor" and high graded woodland (Table 2). This shows dramatically how correct application of ecological knowledge can aid nature and increase productivity. The net growth even during the first 15 years was 128 bd. ft., culls had been reduced to zero, and there was a sharp ingrowth of saplings into pole sizes. Many openings were made and these were soon filled with mixed oaks,

Table 2. Intensive group selection silviculture on 21-acre poor farm woodland demonstration

| | Original stand 1952 | Intensive improvement and group selection cutting, 1952, 1959 | 1967 Inventory |
|---|---|---|---|
| | ---------- per acre ------------ | | |
| Sawtimber volume; trees 11 inches d.b.h. and larger, bd. ft. | 3048 | 1762 | 3190 |
| Number of cull trees 5 inches d.b.h. and larger | 67 | 67 | 0 |
| Number of good growing stock trees 5-10 inches d.b.h. | 36 | 0 | 59 |

hickory, yellow poplar and other miscellaneous timber species. By some standards this area would have been clearcut in 1952. The 1988 slides show a beautiful stand of poles and small sawtimber.

## EARLY REGENERATION AND GROWTH RESPONSE TO INTENSIVE GROUP SELECTION SILVICULTURE

The earliest survey of reproduction in openings was made on 7 compartments of mixed hardwoods (coves and northerly slopes) and 3 compartments of oak hickory (ridges and south slopes) four years after treatment (Minckler and Jensen, 1959). Treatments removed 600 to 1200 bd. ft. per acre of sawtimber plus killing 36 cull trees per acre.

On the 10 areas surveyed there was about 3000 desirable, well-distributed seedlings and seedling sprouts per acre of openings on both sites. There was an additional 3000 of miscellaneous timber and nontimber species in small coves and about 1700 on oak-hickory sites. Yellow poplar reproduced poorly in thick litter and oaks and yellow poplar had more new reproduction and faster growth in the cut openings.

In 1971 with the cooperation and support of the National Parks and Conservation Association, Peter A. Twight, with the help of a forest technician, made a 100 percent inventory of two mixed hardwood compartments totaling 38 acres and with three cutting treatments between 1949 and 1971 (Twight and Minckler, 1972). I surveyed openings for regeneration by milacre plots.

The original stand in 1949 averaged 5579 bd. ft. per acre of merchantable trees 11 inches d.b.h. and above. In the three cuts 3579 bd. ft. were removed and the culls killed. In 1971 the merchantable sawtimber stand was 5763 bd. ft. per acre.

The stand data before and after management are shown in Table 3. The net production on this 38 acres for 22 years after the beginning of management was 171 bd. ft. per acre per year plus elimination of all cull trees, improved stand quality, and the establishment of new regeneration in openings. Note that volume of oaks and yellow poplar increased and that of hickory and miscellaneous species decreased.

The latest regeneration count was made on this area in 1971 in 34 openings on the 38 acres just discussed (Twight and Minckler, 1972). Openings were made by treatment procedures for group selection already discussed. The results show a diversity of species ranging in diameter (at 4.5

Table 3. Total numbers and board foot volume, 1949 and 1971, on 38 acres after 3 cuts totaling 136 M bd. ft. plus killing culls.[1]

| 1949 | Hickory | White Oak | Red Oaks | Yellow Poplar | Miscellaneous | Totals |
|---|---|---|---|---|---|---|
| Number of trees[2] | 982 | 838 | 1,552 | 349 | 862 | 4,593 |
| Board foot volume[3] | 40,090 | 26,340 | 89,220 | 40,000 | 17,020 | 211,670 |
| Percent of trees | 21 | 18 | 34 | 8 | 19 | 100 |
| Percent volume | 19 | 12 | 42 | 19 | 8 | 100 |
| **1971** | **Hickory** | **White Oak** | **Red Oaks** | **Yellow Poplar** | **Miscellaneous** | **Totals** |
| Number of trees[2] | 507 | 829 | 868 | 314 | 107 | 2,625 |
| Board foot volume[3] | 22,192 | 33,687 | 114,725 | 42,240 | 3,280 | 219,124 |
| Percent of trees | 19 | 32 | 33 | 12 | 4 | 100 |
| Percent volume | 10 | 15 | 52 | 21 | 2 | 100 |

[1]Taken from Twight and Minckler, 1972.

[2]Trees 5 inches d.b.h. and above.

[3]Trees 11 inches d.b.h. and above (International 1/4-inch rule).

ft.) from less than one inch to four inches (Table 4). The reproduction in these openings had not been weeded but all openings were cleared of overstory trees

REGENERATION RELATED TO OPENING SIZE

A regeneration study 10 years after cutting in 100 group selection openings on 10 compartments related regeneration to size of openings (Minckler and Woerheide, 1965). Desirable reproduction occurred on all sizes but composition and size of saplings 10 feet and taller was related to opening size and site (Table 5).

The larger opening sizes of 1½ to 2 generally had taller reproduction. Openings of less than 3/4 to 1- size are too small for successful development of regeneration with the possible exception of white oak. The amount of light in group selection openings is highly correlated with opening size (Minckler, Leon, 1961).

Observations of old openings show that crowns of edge trees intermingle, and spacing between edges tends to become normal. Epicormic sprouting of leave edge trees did not occur except on trees with low crown ratios, generally not left as good growers.

SUMMARY

The one-fourth rotation active work before termination could not fulfill all the original objectives of the compartment study. But the 20 years of active research, plus the colored slides taken in 1988 at half rotation, gave substantial results on regeneration and stand growth from intensive group selection silviculture up to 40 years.

The treatment of intensive group selection and stand improvement cuts is described and clarified. Regeneration in small cut openings of 1 to 2 sized or larger was successful in species, numbers, and growth. Patch cutting of larger openings is usually not required or appropriate. A continuous diversified forest is obtained which can gradually be brought to the desired uneven-aged stand structure by diameter distribution control of the management unit. The treated stands of good quality trees have a range of size from saplings (in new openings) to poles and sawtimber. Net volume growth during this management period was good. Stands at half-rotation (1988) are well-stocked and of high quality, as shown by photographs, as no further inventories have been taken since 1968 with one exception, 1971. New inventories of the 38 compartments at half rotation (about 1988 - 1990) would add vital information, and with the cost data already obtained, allow conclusions on the cost results if markets for pulpwood and firewood were now available.

Finally, on eastern mixed hardwood forests the choice is not always "rehabilitate <u>or</u> regenerate" but often rehabilitate <u>and</u> regenerate. This choice should also be based on owner's or public desires and needs. Foresters have flexible actions which are ecologically sound.

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Table 4. Reproduction numbers per acre in 1971 of trees not overtopped in 34 cut openings on the study area. Data after three cuts between 1949 and 1967.

| Diameter at 4.5 ft. | Hickory | White Oak | Red Oaks | Yellow Poplar | Black Gum | Miscellaneous[1] Timber | Miscellaneous[1] Non-Timber | Dogwood | Timber | Species |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 in. | 47 | 34 | 28 | 91 | 41 | 97 | 110 | 28 | 339 | 476 |
| 1" - 2" | 116 | 91 | 34 | 110 | 59 | 66 | 100 | 78 | 476 | 655 |
| 3" - 4" | 50 | 116 | 6 | 69 | 22 | 22 | 3 | 16 | 285 | 304 |
| Total | 213 | 241 | 69 | 270 | 122 | 185 | 213 | 122 | 1100 | 1435 |
| Percent | 15 | 17 | 5 | 19 | 8 | 13 | 15 | 8 | 67 | 100 |

[1]Miscellaneous species are sugar maple, white ash, black cherry, black walnut, sycamore, beech, and elm.

Table 5. Total amount of reproduction 10 feet and taller under canopy and in 100 openings of different sizes 10 years after cutting in 10 compartments

| Species | Under canopy | Opening size[1] 1/4 and 1/2 | 3/4 and 1 | 1-1/2 and 2 |
|---|---|---|---|---|
| **Coves and Northerly Slopes** | | | | |
| | | Number per acre | | |
| Yellow-poplar | 0 | 60 | 330 | 290 |
| White oak | 120 | 180 | 200 | 360 |
| Black and red oaks | 50 | 50 | 70 | 65 |
| Hickory | 240 | 330 | 500 | 450 |
| Miscellaneous desirable | 15 | 30 | 180 | 50 |
| Total desirable | 425 | 650 | 1,280 | 1,215 |
| Miscellaneous undesirable | 100 | 130 | 450 | 630 |
| Miscellaneous shrubs | 360 | 600 | 1,240 | 950 |
| Total undesirable | 460 | 730 | 1,690 | 1,580 |
| **Southerly Slopes** | | | | |
| Yellow-poplar | 0 | 0 | 0 | 0 |
| White oak | 140 | 120 | 235 | 400 |
| Black and red oaks | 10 | 15 | 120 | 130 |
| Hickory | 110 | 210 | 300 | 365 |
| Miscellaneous desirable | 0 | 0 | 0 | 0 |
| Total desirable | 260 | 355 | 655 | 895 |
| Miscellaneous undesirable | 25 | 55 | 80 | 100 |
| Miscellaneous shrubs | 50 | 110 | 340 | 300 |
| Total undesirable | 75 | 165 | 420 | 400 |

[1]Diameter of opening related to height of surrounding trees. Thus, if width of opening is twice the surrounding tree height it is a 2-sized opening.

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# THE EFFECT OF SITE AND AGE ON TREE REGENERATION IN YOUNG UPLAND HARDWOOD CLEARCUTS[1]

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**ABSTRACT.**--The objective of this paper was to determine the distribution of dominant-codominant and dominant plot tree (DPT) regeneration across site and age variables on 74 clearcuts from 5 to 17 years on the Hoosier National Forest. Data was collected on 1801, 0.01 acre regeneration plots. Multivariate and univariate analyses of variance were used to determine if transformed aspect, slope position and clearcut age were significantly related to transformed percent dominant-codominant regeneration. The dominant-codominant regeneration was dominated by miscellaneous noncommercial species, sassafras and yellow-poplar. The DPT regeneration classified as post harvest regeneration was dominated by yellow-poplar, black cherry and red and black oak species. Black cherry followed by yellow-poplar and red and American elm were the most frequently occurring species in the DPT observations classified as advance regeneration. Species composition was significantly related to clearcut age and site variables.

## INTRODUCTION

Clearcutting on the Hoosier National Forest (HNF) has been the harvesting alternative used by the United States Forest Service (USFS) for approximately twenty years. The decision to use clearcutting on the HNF was based on USFS research, completed in the 1950's and early 1960's, and summarized by Roach and Gingrich (1968). This research indicated that if a high priority management objective was to produce high value timber products in a relatively short time, then clearcutting was the most efficient alternative to regenerate most upland hardwood types (Sander and Clark 1971, Roach and Gingrich 1968).

Some foresters and environmental groups have raised concerns that clearcutting is detrimental to the forest. In particular environmental groups suggest that there is a change in species composition from oak dominated stands to a more mixed hardwood regeneration following clear-cutting. The frequency and distribution of regeneration following clearcutting across the array of sites on the HNF is not known and the need for further research in the area of identified in the Hoosier National Forest Land Resource Management Plan (USFS 1986). The specific concern is that foresters cannot predict or control the amount of oak regeneration which will occur following a regeneration harvest. In anticipation of these concerns over clearcutting, Purdue University's Department of Forestry and Natural Resources was contracted by the USFS to evaluate the regeneration of clearcut stands on the Hoosier National Forest (Wayne-Hoosier National Forest, Contract No. 53-52B1-5-01086).

The failure of oak to regenerate successfully after harvesting, especially on more productive sites, is not unique to clearcutting on the Hoosier National Forest (Standiford and Fischer 1980, Heiligmann et. al. 1985, Crow 1988). It appears that regardless of the even-aged management harvesting alternative used, the reproduction of oak follows the trend of little or no reproduction on excellent sites, an occasional occurrence on good sites and moderately plentiful on poorer sites (Trimble and Hart 1961). Mills et. al. (1987) compiled a comprehensive literature review of upland hardwood silviculture with a section especially applicable to the HNF. The reason that current stands on the HNF are

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dominated by oak is not well understood. They concluded that any harvesting activity will reduce the oak component of the future forest with oak regeneration only dominating on poor sites. On better sites they suggest oak will not be a major component of the regeneration and other species will dominate.

Competition among woody stems in young clearcuts is intense with only those trees that can obtain and maintain a dominant crown position surviving to form the overstory of the next forest stand. Once a tree in a young clearcut stand obtains a dominant crown position it has the greatest probability of surviving and maintaining its dominance (Bicknell 1982). Therefore, a seedlings past height growth increment and present crown position are the most significant variables to consider when predicting which seedlings will successfully reach or maintain a dominant crown position (Walters 1963).

This study uses subsets of an empirical data base of 1801, 0.01 acre plots distributed across 74 clearcuts, 5 to 17 years of age on the Hoosier National Forest (Fischer 1987). The purpose of this study was to relate site quality and clearcut age to species composition on the HNF. Specific objectives were to determine the distribution of the dominant-codominant and dominant plot tree species composition in young stands resulting from clearcutting by age and site quality. Dominant-codominant trees were defined as trees with crowns which form the main canopy. Dominant plot trees were the individual tree on each plot with a crown above the main canopy and currently expressing the most height dominance.

## STUDY SITES

Clearcuts of mature, upland hardwood stands made prior to 1981 on the Pleasant Run and Lost River Management Units of the USFS Brownstown R.D. and prior to 1982 on the Little Africa and Tell City Units of the USFS Tell City R.D. were identified from HNF office records. Clearcuts made in pine stands and/or tornado damaged stands were not considered representative of mature, upland central hardwood stands and were dropped from further consideration.

Homoya et. al. (1985) has described the natural regions of Indiana. The Pleasant Run Management Unit (Figure 1) is located in the Brown County Hills Section of the Highland Rim Natural Region. The region is unglaciated with well drained acid silt loam soils of the Berks-Gilpin-Weikert association. The natural vegetation is primarily oak-hickory on the uplands with chestnut oak dominating the overstory of the ridge tops and a thick layer of greenbriar in the understory. The ravines of the Brown County Hills Section contain mesic species such as American beech, red oak, sugar maple and white ash.

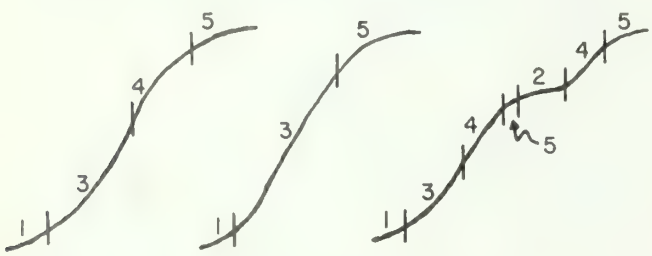
The three remaining units of the HNF, the Lost River, Little Africa and Tell City, Management Units are located in the Crawford Upland and Escarpment Sections of the Shawnee Hills Natural Region. The Crawford Uplands Section's most distinguishing feature is the rugged hills with sandstone cliffs and rockhouses. The major soil association in this section is Wellston-Zanesville-Berks which are well drained acid silt loams. The forest vegetation on the upland slopes are black, chestnut, scarlet and white oaks, and various hickories. The coves contain a mixed mesophytic association represented by species such as American beech, sugar maple, white oak, yellow-poplar and black walnut. Portions of the Lost River and Little Africa Management Units are in the Escarpment Section. The major differences between the Escarpment and Crawford Upland Sections is that the Escarpment section does not contain sandstone cliffs and rockhouses, and post oak along with black oak tends to replace chestnut oak on dry sites. Also, some of the cove species that are found in the Crawford Upland Section are not present in the Escarpment Section.

## METHODS

Two hundred twenty-five clearcuts with complete records that included age, acreage, location and sale sawtimber volume by HNF species group were identified as "qualifying" for field sampling. Seventy-four clearcuts representing a distribution of ages and sites were sampled. A systemic distribution of equi-spaced plots (Husch et. al. 1982) was determined to best represent the irregularly shaped clearcuts on the HNF. Sample plot size was 0.01 acre. The distance between plots was determined to be 3.16 chains using a formula from Husch et. al. (1982) where the sampling intensity was 1 percent and plot size was 0.01 acre. The initial point to begin the inventory on each clearcut was determined from topographical maps to ensure all available site characteristics were equally likely to be included in the inventory. Plots overlapping the boundary of the clearcut were not included in the sample. A total of 1801 plots were sampled.

Plot data collection was divided into three sections. Section 1 was the collection of the site variables of aspect and slope position (fig. 1). Aspect was the plot center's azimuth to the nearest $10^{o}$. Section 2 consisted of a tree tally for each woody stem greater than or equal to 4.5 feet in height, within the boundary of the plot, by species, crown class and origin. Crown classification was an ocular estimate of crown position. Dominants had crowns above the main canopy, codominants had crowns as part of the main canopy and suppressed trees had crowns under the main canopy. Trees classified as seedlings originated from seed, seedling sprouts originated as sprouts from roots or seedlings, and stump sprouts originated from cut stumps. Section 3 was

a more detailed survey of the dominant plot tree in the tree tally section. The DPT was defined as the individual tree on the plot which was currently expressing the most height dominance. If two or more trees were equal in dominance the tree nearest the plot center was chosen. Dominant plot trees were restricted to species which had the potential to reach the main canopy at rotation age (approximately 80 years) thus miscellaneous noncommercial species were excluded. If a plot was dominated by wild grapevines or contained a large residual tree, no DPT was recorded for that plot. The DPT data included: Species, DBH - to the nearest tenth of an inch, Tree Height - to the nearest two feet, Origin - as defined in the tree tally section, Stump Age (one foot above the ground) and DBH Age. An increment borer was used to obtain a core for stump age within one foot of the ground and 4.5 feet in height for the DBH age. Growth rings were counted in the field and the observed age recorded.




| Slope Position Code | Topographic Position |
|---|---|
| 1 | Bottom of Slope |
| 2 | Bench |
| 3 | Mid-Slope |
| 4 | Break from ridge top |
| 5 | Ridge top |

Figure 1. From Bowersox and Ward, 1972; Slope position code numbers for typical topography of the ridge and valley region of Pennsylvania.

## ANALYSIS

Univariate and multivariate analyses of variance were used to test for significant differences between the distribution of species across site and age factors. Univariate analysis was used to test for differences between the means of a single variable across site or age variables, whereas multivariate analysis of variance uses a vector of means to test for significant differences across sites and/or ages (Morrison 1976). The model for the univariate analysis tests for the effect of site/age variables separately on each species. The multivariate analysis of variance model was used when all species were designated as dependent variables an site/age variables were used as independent variables. Wilks' lambda was used as the multivariate test. The Wilks' lambda test uses the determinant of two matrices, which had an approximate F statistic distribution, to test for a significant difference between the vector of means of the dependent variables (SAS Institute 1985).

The analyses and subsequent results of this study are from a more extensive investigation of variables which were found to be related to the species composition of young clearcuts on the HNF (Fischer 1987). For consistency with Fischer's study, and since the dominant-codominant regeneration best indicates the species that have become established and will dominate on each plot, the suppressed trees were not included in the analyses. Also, Fischer (1987) concluded that the similarities between the Shawnee Hills and the Highland Rim Natural Regions exceeded the differences and would allow for the analysis of the data from the plots on the four management units to be combined.

For statistical analysis of the aspect variable the aspect azimuth for each plot was transformed to a scale using the Beers et. al. (1966) aspect transformation procedure:

$$A' = \text{Cos.}\ (45 - A) + 1$$

where

$A'$ = transformed aspect value,
Cos. = cosine,
and $A$ = observed azimuth.

This transformation assumes that azimuth 45$^{\circ}$ (northeast) is the most favorable aspect for tree growth.

To obtain a more balanced distribution of plots by slope position and for comparisons with other central hardwood regeneration studies (Hilt 1985, Heiligmann et. al. 1985), the five slope positions (fig. 1) were reduced to three. Slope positions 1 and 2, bottom and bench slope positions, were combined into a "lower slope position" (251 plots). The "mid-slope position," position 3, was left intact (1101 plots). Slope positions 4 and 5, a break just over a ridge and ridge top slope positions, were combined into an "upper slope position" (449 plots).

The distribution of plots into single year age classes for the clearcut stands inventoried showed an unequal distribution. To obtain a more even distribution of plots with respect to age, plots were divided into four age-class categories: 5-7, 8-11, 12-14, and 15-17 years of age. With the four age groups there are 504 plots in the 5-7 years of age group, 391 plots in the 8-11 age group, 504 plots in the 12-14 age group and 402 plots in the 15-17 years of age group.

Fifteen species/species groups (the term "species" will be used here after to refer to species/species groups) were stratified across aspect codes, slope positions and age groups. The fifteen species are: (1) white oak (white and chinkapin oaks), (2) northern red and black oak, (3) other oak (chestnut, scarlet, pin and post oaks), (4) yellow-poplar, (5) black cherry, (6) black walnut, (7) white ash, (8) hickory (bitternut, mockernut, pignut and shagbark hickories), (9) soft maple (red and silver maples, and boxelder), (10) sugar maple, (11) red and American elms, (12) sassafras, (13) aspen, (14) other commercial hardwoods (basswood, butternut, blackgum, sweetgum, hackberry, locusts and sycamore) and (15) miscellaneous noncommercial (bluebeech, redbud, devil's walking stick, dogwood, hawthorn, ironwood and pawpaw).

## RESULTS

### Dominant-Codominant Regeneration

For the analysis of the dominant-codominant regeneration importance values were derived by:

$$IV_i = (((D_i/D) + (F_i/F)) / 2)* 100$$

where

$i$ = 1,12
$IV_i$ = species importance value,
$D_i$ = density of a species,
$D$ = sum of densities,
$F_i$ = frequency of a species,
and $F$ = sum of frequencies.

The importance value is an "indication of the vegetational importance of a species within the stand" (Curtis and McIntosh 1951). The importance value formula compensates for species which tend to be clumpy and whose presence is then over emphasized when only percentage values are used as a measure of dominance.

The ranking of importance values are: miscellaneous species followed by sassafras and yellow-poplar (table 1). Together these three species have an importance value of 49.9. Surprisingly, the fourth highest ranking species was sugar maple. The combined importance value for the three oak species is 10.2. The other oak (primarily chestnut oak) and black walnut species were the least important of the fifteen species.

Multivariate and univariate analysis of variance using Wilks' lambda and an F statistic (all statistical tests were at the 0.05 level) were used to determine the effect of transformed aspect, slope position and age on the percentage of dominant-codominant trees in a given species. For this analysis the percent of each species on a plot was transformed by the formula:

Table 1.--Density, and frequency of occurrence on 1801, 0.01 acre plots and importance values (I.V.) for dominant-codominant regeneration by species on the Hoosier National Forest clearcuts.

| Species | Density | Frequency | I.V. |
|---|---|---|---|
| white oak | 599 | 308 | 2.9 |
| red and black oak | 1361 | 539 | 5.6 |
| other oak | 536 | 127 | 1.7 |
| yellow-poplar | 4010 | 954 | 12.6 |
| black cherry | 1425 | 678 | 6.6 |
| black walnut | 48 | 30 | 0.3 |
| white ash | 1514 | 570 | 6.1 |
| hickory | 374 | 215 | 2.0 |
| soft maple | 1187 | 314 | 3.9 |
| sugar maple | 2304 | 719 | 8.3 |
| red and Am. elm | 1610 | 498 | 5.8 |
| sassafras | 4591 | 991 | 13.8 |
| aspen | 6261 | 171 | 2.1 |
| other hardwoods | 1108 | 441 | 4.6 |
| miscellaneous | 9115 | 1348 | 23.5 |
| Total | 30408 | 7903 | 100.0 |

$$TP_i = \text{ARCSIN} \sqrt{\% \text{ spp}_i}$$

where

$i$ = 1,12
$TP_i$ = transformed percent by species,
and $\%\ spp_i$ = percent dominant-codominant species on each plot.

The results shown in table 2 reveal that the overall effect of the interaction was significant. Since the three factor interaction of aspect, slope position and clearcut age was significant for all species except black walnut, the effect of the main factors and two-way interactions (not shown in table 2) are not clear. However, slope position appears to be the most important main factor. The two-way interaction of slope position and clearcut age was significant for black walnut indicating that slope position and age interactively effect the distribution of black walnut while aspect did not.

### Dominant Plot Tree

For the analysis of the dominant plot trees (DPT) data the species were reduced to 12 instead of the fifteen species used in the dominant-codominant analysis. The adjustments to the species categories were: a) to combine the black walnut and white ash species, b) to combine the hickory species with the other commercial hardwoods, and c) to exclude the miscellaneous species (see methods). Also, time constraints

necessitated a reduction in the sampling intensity of the DPT age on the Tell City Ranger District. On this district the age of the DPT was obtained only on every fifth plot. All other data on the DPT were collected on these plots. This reduction in sampling intensity accounted for 440 of the 1801 plots. These plots were removed from the DPT data base. Also, 39 plots did not have a DPT thus the DPT data base has 1322 plots.

Since the above ground age, at one foot, of each DPT was collected it was possible to determine which trees were advance regeneration. For this study advance regeneration was defined as any DPT that had an age at one foot which was three years or greater than the overall clearcut age. This age was chosen since most HNF cutting contracts ranged over a two or three year period. The observations which were determined to be advance regeneration were sorted into a separate data base. The data base without the advance regeneration (hereafter referred to as "post harvest regeneration") consists of 1071 observations while the advance regeneration data base has 251 observations. Since there was not any attempt to age DPT below stump height (one foot), it is possible that some of the observations that were classified as post harvest regeneration could be advance regeneration. The origin of these misclassified observations could be from trees that had died back or were broken off during the logging operation and then resprouted below one foot after harvest.

Table 2.--Significance of F test by species and Wilk's lambda for the overall effect by aspect, slope position (sl. pos.), age and the three-factor interaction on transformed percentage of dominant-codominant regeneration.

| Species | Aspect | Sl. pos. | Age | Aspect x sl. pos. x age |
|---|---|---|---|---|
| white oak | *[1] | ns | * | * |
| red and black oak | * | * | ns | * |
| other oak | * | * | * | * |
| yellow-poplar | * | ns | * | * |
| black cherry | ns[2] | * | * | * |
| black walnut | ns | * | ns | ns |
| white ash | ns | * | * | * |
| hickory | * | ns | ns | * |
| soft maple | ns | * | ns | * |
| sugar maple | ns | * | ns | * |
| red and Am. elm | * | * | * | * |
| sassafras | ns | * | ns | * |
| aspen | ns | * | ns | * |
| other hardwoods | ns | * | * | * |
| miscellaneous | ns | ns | * | * |
| Overall effect | * | * | * | * |

[1]* - significant at the 0.05 level
[2]ns - not significant

The seedling and seedling sprouts origin categories were combined because of the difficulty in distinguishing between the two classifications, especially after a clearcut was ten years of age. Also, since there could only be one DPT per plot, importance values are not possible on a plot basis, therefore, percent values were used.

**Post Harvest Regeneration**

In table 3 it is evident that yellow-poplar is the dominate species in the post harvest regeneration category. Red and black oak and black cherry are the second and third highest percent species followed by aspen and sassafras. The three oak species together make up 18.8 percent of the DPT post harvest regeneration. The results suggest that the species composition is currently dominated by shade intolerants with the rest of the species relegated to a subordinate role in clearcuts 5 to 17 years of age.

The origin of the species shows that yellow-poplar, black cherry, red and American elm and sassafras trees were primarily from seedling/seedling sprouts. All of the aspen were from seedling/seedling sprouts. The white oak, and red and black oak species are almost equally split between seedling/seedling sprout and stump sprouts. The other oak species had the highest percent of stump sprouts at approximately 67 percent.

**Advance Regeneration**

The 251 observations which were identified as advance regeneration were analyzed in the same format as the post harvest regeneration data to allow for comparisons between the results of both data bases. For these data black cherry is dominant followed by yellow-poplar (table 4). The percentages of black cherry and yellow-poplar in the advance regeneration (table 4) have almost been reversed from the post harvest regeneration data (table 3). The percent red and black oak is much lower for advance regeneration than post harvest regeneration. The three oak species make up 12.2% of the DPT advance regeneration.

The average percent of seedling/seedling sprouts and stump sprouts are approximately equal from one data base to the other (tables 3 and 4). As in the post harvest data all of the aspen observations are from seedling/seedling sprout origin. However, in contrast to the post harvest data where the majority of the sugar maple observations are from stump sprout origin all of the observations in the advance regeneration data are from seedling/seedling sprout origin.

Table 3.--Percent of dominant plot trees by species group and percent by origin of each species for observations classified as post harvest regeneration. (n = 1071)

| Species | Percent | Percent by origin | |
|---|---|---|---|
| | | Seedling/ seedling sprout | Stump sprout |
| white oak | 2.7 | 55.2 | 44.8 |
| red and black oak | 11.6 | 46.3 | 53.8 |
| other oak | 4.5 | 33.3 | 66.7 |
| yellow-poplar | 37.7 | 88.3 | 11.7 |
| black cherry | 10.7 | 93.9 | 6.1 |
| walnut and ash | 4.7 | 61.4 | 38.6 |
| soft maple | 3.0 | 56.3 | 43.7 |
| sugar maple | 1.5 | 43.8 | 56.2 |
| red and Am. elm | 5.9 | 85.7 | 14.3 |
| sassafras | 7.0 | 86.5 | 13.5 |
| aspen | 8.2 | 100.0 | 0.0 |
| other hardwoods | 3.0 | 59.4 | 40.6 |
| Average | | 77.6 | 22.4 |

Table 4.--Percent of dominant plot trees by species group and percent by origin for each species for observations classified as advance regeneration. (n = 251)

| Species | Percent | Percent by origin | |
|---|---|---|---|
| | | Seedling/ seedling sprout | Stump sprout |
| white oak | 5.6 | 78.6 | 21.4 |
| red and black oak | 4.4 | 63.6 | 36.4 |
| other oak | 2.8 | 57.1 | 42.9 |
| yellow-poplar | 14.8 | 73.7 | 26.3 |
| black cherry | 31.6 | 88.6 | 11.4 |
| walnut and ash | 5.2 | 84.6 | 15.4 |
| soft maple | 5.6 | 50.0 | 50.0 |
| sugar maple | 6.8 | 100.0 | 0.0 |
| red and Am. elm | 8.4 | 95.0 | 5.0 |
| sassafras | 6.4 | 62.5 | 37.5 |
| aspen | 1.6 | 100.0 | 0.0 |
| other hardwoods | 6.4 | 71.6 | 29.4 |
| Average | | 80.0 | 20.0 |

## DISCUSSION AND CONCLUSIONS

The species composition of the dominant-codominant regeneration in clearcuts 5-17 years of age on the Hoosier National Forest is dominated by intolerant species such as sassafras and yellow-poplar as well as many miscellaneous noncommercial species. These results are consistent with other authors' conclusions from similar studies (Standiford and Fischer 1980, Beck and Hooper 1986, Hilt 1985).

Hilt (1985) used multivariate and univariate analysis of variance to test for the effect of site and age on five species groups. He found the overall effect of age, site and the interaction of age and site significant at the 0.05 level. Hilt's univariate results for the effect of age, site and the interaction of age and site for oaks, yellow-poplar, maples, other commercial hardwoods and noncommercial hardwoods were that age was only significant for noncommercial species, while site was significant for the oaks and other commercial species. The interaction of site and age was only significant for the oak species.

A direct comparison between Hilt's results and the results reported here is not possible because Hilt used site index for a measure of site quality, while the site variables used in this study were aspect and slope position. Also, Hilt chose to group species into far fewer classes. In our results the significance of the aspect, slope position and age interaction precludes any attempt to separate the effects of any other the main factors, except for black walnut. The difference results in the two studies may be because Hilt only inventoried stands with at least 60 percent oak sawtimber volume before harvest, while in the HNF study the percent of preharvest oak sawtimber volume averaged only 54 percent (Fischer 1987).

Two conclusions can be made about the species composition of the dominant-codominant regeneration on the HNF. First, since the overall effect was significant (table 2), the species composition of the young clearcuts differs across sites and age. Secondly, no one single factor of aspect, slope position or age can be solely contributed to changes in species composition. These conclusions verify why simplistic, single factor prediction models have not succeeded in aiding foresters to predict regeneration response to clearcutting in the upland central hardwoods.

The dominant plot tree (DPT) represents the tree on each plot that will most likely survive and dominate a plot over time (Bicknell 1982, Fischer 1987). Overall, 81 percent of the DPT observations were classified as post harvest regeneration and only 19 percent as advance regeneration. The order of dominance by species for the post harvest DPT is yellow-poplar followed by red and black oak, and black cherry. In the advance regeneration data black cherry is dominant followed by yellow-poplar and red and American elm. The most obvious difference between the species composition of the post harvest regeneration and advance regeneration data base are the changes in percentages of yellow-poplar

and black cherry. Also, oaks were a higher percentage of the post harvest regeneration than the advance regeneration.

A comparison of the dominant-codominant to the post harvest DPT regeneration reveals that DPT regeneration is more dominated by yellow-poplar and oaks (tables 1 and 3). When comparing dominant-codominant to advance DPT regeneration, the DPT regeneration is more dominated by black cherry (tables 1 and 4). Interestingly, while sassafras has the second highest importance value (13.8) for dominant-codominant regeneration its percentage of dominant plot trees is only 7.0 and 6.4 for post harvest and advance regeneration.

Obviously, these differences in composition between dominant-codominant and DPT are partially the result of not recording miscellaneous species as DPT. However, this difference is also the expression of height domination by species which are emerging above the canopy. As Hilt (1985) suggests in addition to yellow-poplar other species such as black cherry, aspen and white ash indicate the same trend of expressing early height dominance. If the species composition of the DPT regeneration is indeed the better indicator of the future composition as suggested by Bicknell (1982), then several conclusions can be made. First, the next forest will have a large component of yellow-poplar and black cherry. Secondly, although the next forest will apparently have a smaller component of oak than the harvested stands (Fischer 1987), the situation is not hopeless. Based on DPT the oak species will make up approximately seventeen percent of the stems in the next forest instead of the ten percent predicted if percent dominant- codominant stems is used as an indicator.

Finally, several questions on the long-term development trends of these HNF clearcuts remain unanswered. One question that seems to persist is whether, after clearcutting, mesic site species have extended their range on to sites that may not support them in times of stress (Leopold and Parker 1985). Hilt (1985b) noted high mortality of yellow-poplar following drought years in 20+ year-old stands resulting from clearcutting on poor and medium sites in southeast Ohio. Fischer (1987) found that preharvest yellow-poplar saw-timber volumes only averaged seven percent of the total on these HNF clearcuts. Current levels in the dominant-codominant and DPT regeneration are two to five times higher. Also, Fischer (1987) observed that extensive 0.5 to 1 acre patches of aspen and black locust occur on some HNF clear-cuts. Since these species do not generally persist over the entire length of a rotation (80-120 years), it is unclear what species will be present in these patches at rotation age. Obviously long term data from permanent plots would go far in answering many of the questions that remain about the dynamic process of species composition in upland hardwood clearcut stands.

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# EFFECTS OF UNDERSTORY REMOVAL IN THINNED UPLAND OAK STANDS -- 22-YEAR RESULTS[1]

Donald E. Hilt, David L. Sonderman, and Everette D. Rast[2]

Abstract.--Dense understory develops in thinned upland oak stands and potentially competes with overstory trees for moisture and nutrients. To test this hypothesis, we examined the 22-year results of six plots in a 52-year-old stand thinned to 60 percent of normal stocking in 1963. The understory trees on three of the plots were removed by cutting and spraying with an herbicide. After 22 growing seasons, understory trees were larger and taller on the untreated plots. Understory removal treatments altered the species composition of the understory but did not prevent its reestablishment. Growth of overstory trees was not increased by removing the understory. Understory removal is not recommended as a viable management alternative to increase the growth of overstory trees.

## INTRODUCTION

When an even-aged upland oak stand is thinned to 60 percent or lower relative stand densities, a dense understory often develops in response to the increased sunlight. The understory originates from (1) advanced regeneration, (2) sprouting from stumps of recently-cut trees and advanced regeneration damaged in logging, and (3) seedlings that develop from dormant seeds in the litter and seeds that are newly deposited in the exposed mineral soil. As this understory develops, it may compete with the overstory for moisture and nutrients. We do not know the long-term effects of this understory on the growth of the residual trees, or if the effects are great enough to influence forest management.

The data analyzed in this report were from a study established in a 52-year-old, even-aged, upland oak stand in southeastern Ohio in 1963. Ten-year results were reported by Dale (1975). No significant effects due to understory removal were evident at that time. However, the effects of silvicultural treatments sometimes change over time. After 22 years, the thinned stands in this study have now closed, and the effects of understory removal on the growth of residual trees can be considered conclusive. The long-term results also provide valuable information on the growth and yield of thinned upland oak stands, as well as on the species composition, quantity, and size of the understory that develops.

## THE STUDY

Six 0.25-acre plots were established in a 52-year-old, fully-stocked, even-aged, upland oak stand in southeastern Ohio in 1963. A randomized block design with two plots in each of three blocks was used. Site index was uniform across all plots, and averaged 73 feet according to Schnur's (1937) site index curves. Species composition was typical for an upland oak stand of this age and site--primarily scarlet oak, black oak, and chestnut oak, with some white oak, and a few hickory and yellow-poplar trees (Little 1979).

All six plots were thinned to the 60-percent stocking level according to the tree-area-ratio equation (Gingrich 1967). This stocking level was selected because it (1) opens the crown canopy enough to allow adequate light for understory development, and (2) was thought to be about the lowest level of stocking for full site utilization. The major consideration during thinning was to leave the specified stocking level

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distributed on the best trees as evenly spaced as possible throughout the plot. Within this framework, noncommercial species such as dogwood, sourwood, sassafrass, and blackgum, commercial species in the lower crown classes, and larger trees with stem deformities (forks, crook, and sweep) were removed first. Some of these less desirable trees had to be left to achieve uniform spacing.

After thinning, an understory removal treatment was applied to one plot in each of the three blocks. The understory was defined to be all trees less than 2.6 inches dbh in 1963. Treatment consisted of two phases: (1) all stems less than 2.6 inches were removed by cutting immediately after thinning, and (2) any resprouting that occurred was killed the following spring by mist blowing each plot with 2, 4, 5-T in a solution of 40 lbs (AI)/gal of No. 2 diesel fuel. Misting killed the sprouts without damage to the overstory trees. The understory was not removed on the corresponding untreated plots in each block. An isolation strip 30 feet wide surrounded each plot and received the same treatment as the plot.

All residual overstory trees greater than or equal to 2.6 inches dbh were numbered for remeasurement so that future mortality and ingrowth could be determined. Dbh was measured initially and at various yearly intervals on these trees through 1985. The total number of overstory trees and their respective basal areas per acre were nearly identical for the untreated and treated plots after thinning in 1963 (table 1). Species composition varied slightly with untreated plots having more white oaks and the treated plots having more chestnut oaks.

Understory trees were numbered and measured accordingly as they grew larger than the 2.6-inch diameter limit. In 1985, we also recorded the species and dbh of all trees taller than 4.5 feet (but less than 2.6 inches in diameter) to gain more insight on the development of the understory. Heights of these smaller trees and any trees that grew larger than 2.6 inches were measured with a telescoping pole.

Table 1.--Number and basal area (BA) of overstory trees following thinning for plots with untreated and treated understories.

| Species | 1963 Number | 1963 BA | 1985 Number | 1985 BA |
|---|---|---|---|---|
| | No/ac | $Ft^2/ac$ | No/ac | $Ft^2/ac$ |
| | | UNTREATED | | |
| White oak | 30.7 | 8.5 | 25.3 | 11.9 |
| Black oak | 48.0 | 19.3 | 37.3 | 30.1 |
| Scarlet oak | 85.3 | 37.3 | 68.0 | 62.0 |
| Chestnut oak | 5.3 | 2.5 | - | - |
| Yellow-poplar | 2.7 | 1.1 | 1.3 | 1.3 |
| Hickory | 2.7 | 0.4 | 2.7 | 0.8 |
| Total | 174.7 | 69.1 | 134.6 | 106.1 |
| | | TREATED | | |
| White oak | 12.0 | 2.6 | 9.3 | 3.2 |
| Black oak | 44.0 | 18.8 | 38.7 | 32.7 |
| Scarlet oak | 72.0 | 33.6 | 50.7 | 45.5 |
| Chestnut oak | 41.3 | 11.7 | 29.3 | 15.3 |
| Yellow-poplar | 8.0 | 2.0 | 8.0 | 3.5 |
| Total | 177.3 | 68.7 | 136.0 | 100.2 |

Overstory trees were graded in 1985 using the provisional grade specifications for hardwood growing-stock trees (Boyce and Carpenter 1968). This grading system applies to pole-size stands because all trees larger than 7.0 inches dbh with a potential 12-foot butt log are assigned a grade. Grades are based on the probability of the tree yielding a Grade 1, 2, or 3 butt log when it reaches 16 inches dbh. Below-grade trees were classified as Grade 4.

## RESULTS

### Understory Development

Considerable understory developed in both the untreated and treated plots (table 2). The difference in the total number of trees per acre, 1428 for the untreated plots and 1447 for the treated plots, was not significantly different ($p>0.05$). However, basal areas per acre were significantly different ($p>0.05$), averaging 11.70 and 7.31 square feet for the untreated and treated plots, respectively. Given that the number of understory trees per acre was the same, the difference in basal areas can be attributed to the presence of larger understory trees on the untreated plots. Average dbh was always greater on the untreated plots, regardless of species (table 2). A graph of the number of trees in each 0.5-inch dbh class clearly illustrates the presence of larger trees on the untreated plots (fig. 1). The two distributions were significantly different ($p>0.05$) based on a chi-square test for equality. We conclude that the effect of understory removal was to delay the development of understory growth; however, it did not prevent the reestablishment of the understory.

Understory removal treatments substantially altered understory species composition (table 2). There was a major increase in the amount of sassafras on the treated plots. Sassafras is a prolific seeder that established itself quickly on disturbed soil. Sassafras, and to a lesser degree, sourwood and yellow-poplar, seemed to replace blackgum and dogwood, both of which were present in greater numbers on the untreated plots. The difference in the number of commercial trees per acre was not significant ($p>0.05$), averaging 243 and 264 for the untreated and treated plots, respectively.

Heights of understory trees tabulated by 5-foot height classes clearly indicate the presence of taller trees on the untreated plots (table 3). Nineteen percent of the trees on the untreated plots were taller than 15 feet, compared to only 11 percent on the treated plots.

### Overstory Development

The number of overstory trees per acre in 1985

Table 2.--Number, basal area (BA), and average DBH of understory trees in 1985, 22 years after thinning, for plots with untreated and treated understories.

| Species | Untreated | | | Treated | | |
|---|---|---|---|---|---|---|
| | Number | BA | Dbh | Number | BA | Dbh |
| Commercial | No./ac | Ft² ac | In. | No./ac. | Ft² ac | In. |
| Oaks | 44 | 0.46 | 1.2 | 40 | 0.14 | 0.7 |
| Yellow-poplar | 13 | .39 | 1.8 | 48 | .12 | 0.5 |
| Red maple | 83 | .86 | 1.1 | 93 | .46 | [illegible] |
| Hickory | 87 | .70 | 1.0 | 52 | .10 | 0.5 |
| Other commercial[1] | 16 | .13 | 1.1 | 31 | .24 | 1.0 |
| Total commercial | 243 | 2.54 | 1.2 | 264 | 1.06 | 0.7 |
| Noncommercial | | | | | | |
| Black gum | 369 | 2.82 | 1.0 | 169 | .61 | 0.7 |
| Dogwood | 667 | 4.17 | 0.9 | 496 | 1.53 | 0.6 |
| Sourwood | 48 | 1.42 | 2.1 | 124 | 2.45 | 1.7 |
| Sassafras | 89 | 0.63 | 1.0 | 352 | 1.59 | 0.8 |
| Other noncommercial[2] | 12 | .11 | 0.9 | 41 | .06 | 0.4 |
| Total noncommercial | 1128 | 9.16 | 1.2 | 1183 | 6.24 | 0.9 |
| Overall Total | 1428 | 11.70 | 1.2 | 1447 | 7.31 | 0.8 |

1/ White ash, American beech, basswood, sycamore, sugar maple.

2/ Hazelnut, serviceberry, red bud, Ohio buckeye, American chestnut, cucumber tree.

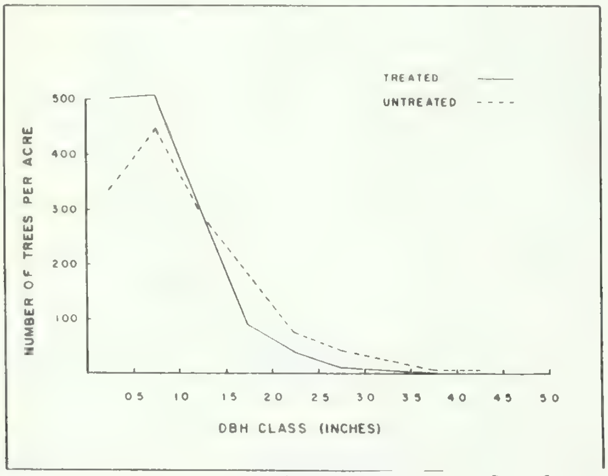


Figure 1--Diameter (dbh) distribution of understory trees in 1985, 22 years after thinning.

Table 3.-- Number of understory trees per acre in each 5-foot height class in 1985, 22 years after thinning, for plots with untreated and treated understories.

| Height class | Untreated | Treated |
|---|---|---|
| 0-5 | 169 | 201 |
| 6-10 | 551 | 697 |
| 11-15 | 433 | 393 |
| 16-20 | 213 | 128 |
| 21-25 | 33 | 20 |
| 26-30 | 23 | 7 |
| 31-35 | 5 | 1 |
| 36-40 | 1 | 0 |
| Total | 1428 | 1447 |

was nearly identical for untreated and treated plots, averaging 134.6 for the untreated plots and 136.0 for the treated plots (table 1). Although ending basal areas averaged 106.1 square feet for the untreated plots and 100.2 square feet for the treated plots, they were not significantly different (table 4). The reason for the difference in basal areas is the increased mortality of scarlet oak on the treated plots (fig. 2). Some of the larger scarlet oaks began dying at age 67. Since this increased mortality occurred nearly 15 years after thinning, we cannot attribute its cause to the understory removal treatment.

Table 4.--Basal areas, basal area growth, and mortality of overstory trees over 22 years for plots with untreated and treated understories.

| Item (Ft²/Ac) | Untreated | Treated | Difference | Significance* |
|---|---|---|---|---|
| Basal area 1963 | 69.1 | 68.7 | 0.4 | N.S |
| Basal area 1985 | 106.1 | 100.2 | 5.9 | N.S |
| Gross growth[1] | 52.1 | 50.2 | 2.3 | N.S |
| Mortality | 15.6 | 19.2 | -3.6 | N.S |
| Net growth | 36.9 | 30.7 | 6.2 | N.S |

1/ Growth rates computed for the 22-year study period are appropriately termed accretion--they include growth on trees that later died.

*Significance level -- 0.05.

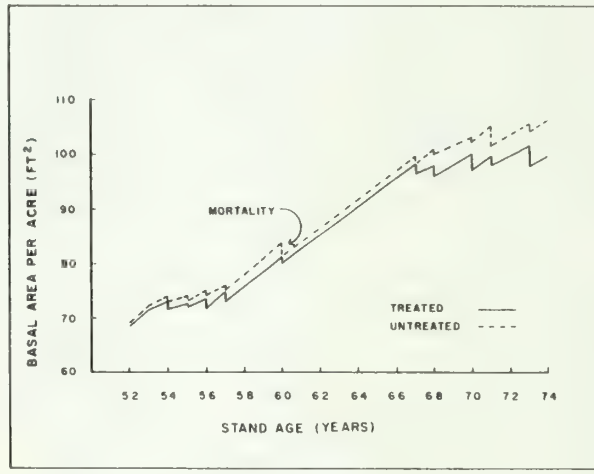


Figure 2--Relationship between overstory basal area and stand age for thinned plots with untreated and treated understories.

The slope of the lines between measurements in Figure 2 indicates gross stand growth (survivor growth). Gross basal area growth per acre was nearly the same in the untreated and treated plots for any measurement period, as indicated by the parallel lines. Gross growth for the entire 22-year period was not significantly different ($p>0.05$) for the treated and untreated plots (table 4). Mortality and net growth were not significantly different either ($p>0.05$). We conclude that understory removal had no effect on the stand growth of the overstory trees.

Diameter growth rates of the largest 40 trees per acre are plotted for five measurement periods in Figure 3. Comparisons of diameter growth rates should be made on an equal number of crop trees per acre (Adams and Chapman 1942; Smith 1962; Hilt 1979). The 40 largest trees per acre are commensurate with the European standard of 100 trees per hectare. Diameter growth rates were not significantly different ($p>0.05$) between the untreated and treated plots for any of the measurement periods. Since growth rates were slightly larger on the untreated plots, we conclude that the understory removal had no effect on the diameter growth of the larger trees.

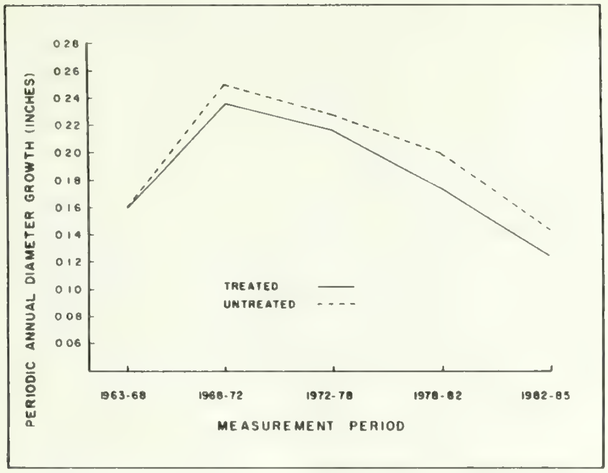


Figure 3--Periodic annual diameter growth rates of the largest 40 trees per acre for thinned plots with untreated and treated understories.

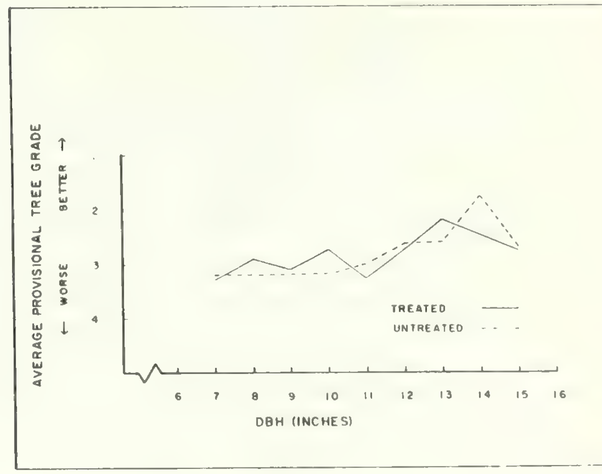


Figure 4--Average potential tree grades in 1985, 22 years after thinning, for trees in thinned plots with untreated and treated understories.

It has been suggested that an abundant understory shades the boles of the overstory trees and increases the quality of the overstory trees because of the early death of existing and epicormic branches (Dale and Sonderman 1984). Since the trees were not graded in 1963, we could not analyze grade changes. However, provisional tree grades in 1985 indicated no differences between the untreated and treated plots (fig. 4). The only trend was an increase in provisional grade with increasing dbh. This trend was similar for both the untreated and treated plots, and indicates that the highest quality trees at age 74 were also the largest trees.

## CONCLUSIONS

A dense understory develops in upland oak stands that are thinned to 60 percent and lower relative stand densities. The untreated plots in this study still had nearly 1,400 understory stems per acre 22 years after thinning. This understory could presumably compete with the overstory trees for moisture and nutrients. A single understory removal immediately after thinning failed to prevent the reestablishment of the understory. Some resprouting can be expected, and, additional regeneration can be expected from the seed sources in the litter that respond to the disturbed soil and increased sunlight. Sassafras quickly established itself on the treated plots in this study. After 22 years, the understory trees on the treated plots were smaller in diameter and shorter than understory trees on untreated plots. However, understory density in the treated and untreated plots was the same with nearly 1,400 trees per acre.

The one-time understory removal treatment did not have any effect on the growth or quality of the overstory trees. Gross basal area growth per acre, net growth, and mortality were not significantly different between treated and untreated plots. Diameter growth rates of the largest 40 trees per acre were actually slightly larger on untreated plots. Potential tree grades assigned after 22 years indicated no difference in tree quality due to treatment.

It may be argued that understory removal in this study did not affect overstory growth because the understory reestablished itself and should have been removed again. While this argument has some merit, the high cost of herbicide treatments makes repeated applications unprofitable. In our opinion, if understory removal is to be practical, it should be applied only once after each thinning.

Forest land managers should be aware of the dense understory that develops after thinning. However, we cannot recommend understory removal in thinned stands as a viable management practice because understory removal did not increase the growth of overstory trees. Because of the negative attitudes toward the use of herbicides, herbicide use is appropriate only when a specific result is desired, or under intensive management where repeated applications are economically possible.

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CAUTION

This publication reports research involving herbicides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of herbicides must be registered by appropriate State and/or Federal agencies before they can be recommended.

Herbicides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all herbicides selectively and carefully. Follow recommended practices for the disposal of surplus herbicides and herbicide containers.

EARLY THINNING CAN IMPROVE YOUR STAND OF

COPPICE-REGENERATED OAK[1]

K.E. Lowell, H.E. Garrett[2], R.J. Mitchell[3]

Abstract.--Data from a long-term study established in a coppice-regenerated oak stand in the Missouri Ozarks demonstrated that: 1) superior stump sprouts can be identified as early as age 5, 2) thinning of sprouting clumps will significantly increase the diameter and volume growth of selected sprouts, and 3) the advantages of early thinning of clumps to single dominant sprouts remain evident at age 30. A series of curves are presented that provide a basis for making recommendations concerning the early clump thinning of coppice-regenerated oak stands.

## INTRODUCTION

Obtaining adequate oak reproduction in even-aged upland hardwood forests is a widespread problem in the Central Hardwoods Region (Bowersox and Ward 1972, Sander et al. 1984). As a result, advanced regeneration in harvested oak stands is often considered to be the most important component in stand regeneration. Because oaks are prolific sprouters, many trees originate from stumps, and often these large seedling-sprouts grow rapidly (Johnson 1977, 1979, Zahner and Myers 1984).

Unfortunately, despite the importance of these coppice-stems, little is known about the long-term growth and development of coppice-regeneration in oak stands or about the effect(s) of silvicultural treatment(s) on such regeneration. Perhaps the best discussion of these topics are two guides prepared by the USDA Forest Service for advanced oak regeneration (Sander et al. 1976, Sander et al. 1984). However, due to data limitations neither of these guides were able to discuss the long-term development of coppice-regenerated oak stands or the effects of silvicultural treatment on these stands.

This lack of information presents an obvious problem to the forest manager -- if a stand of young (less than 10 years) coppice-regenerated oak is not growing as desired, what should be done? Will a clump thinning on each sprouting stump improve the growth of residual sprouts to the desired level? If so, will the effects remain evident as the stand grows older, or will the improved growth be a short-lived phenomenon? Or, rather than conducting a thinning, is it better to allow the stand to grow until some trees are large enough that a harvest for posts and poles or firewood is possible and then regenerate the stand (naturally or artificially) after harvest?

Long-term studies of the growth and development of coppice-regenerated oak stands are needed to answer these questions. Though such studies are rare, data collected from one study initiated in the Missouri Ozarks in the early 1950s can contribute valuable information to this topic. The purpose of this paper is to present the results of a long-term study of the effects of clump thinning on coppice-regenerated oak stands and to describe a technique for evaluating the probable results of clump thinning on stand development.

## MATERIALS AND METHODS

Data were collected from University Forest, a 7200-acre forested tract located in southeastern Missouri and owned by the University of Missouri. The 3-acre study area was

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of medium quality -- site index 60 to 65 feet base age 50 for red oaks. In 1953, the entire study area was clearcut. Before clearcutting, the age of the stand was approximately 32 years. After clearcutting, the stand regenerated vigorously through stump sprouts. Predominant tree species were scarlet oak (Quercus coccinea Muench.), black oak (Quercus velutina Lam.), southern red oak (Quercus falcata Michx.), white oak (Quercus alba L.), post oak (Quercus stellata Wangenh.), and hickory (Carya spp.) which comprised 34%, 17%, 5%, 23%, 13%, and 8%, respectively, of the regenerated stems.

Three 1.0 acre blocks subsequently were established and each block divided into four 0.25 acre sub-plots. These sub-plots included a 23 foot buffer strip leaving a 0.147 acre measurement plot. In each block, treatments were assigned randomly: one plot was selected for an unthinned control, one for thinning, and two were not used. Five years after clearcutting, a single dominant stem on each sprouting stump was selected and tagged in both the control and thinned plots. In the thinned plots, every multiple-stemmed sprout clump was thinned to a single dominant stem. No single stems were cut, and stumps producing single stems were not included in this study. In the control plots no thinning was done. Thinned plots averaged 600 (selected dominant) stems per acre after thinning and unthinned plots averaged 740 (selected dominant) stems per acre. At age 5, species, diameter of the parent stump at the point of cutting (7 inches above ground), the number of sprouts on the stump, and height of each selected sprout were recorded. At age 30 (25 years after thinning), diameter at breast height (dbh) was measured to the nearest 0.1 inch and mortality of all selected sprouts was inventoried. Dominant sprout heights were also sub-sampled at age 30.

A forest manager is not likely to manage all existing stems in young stands throughout a rotation, but instead is likely to concentrate efforts on those that show the most promise at the time of thinning. Moreover, to gain a thorough understanding of how clump thinning can improve the growth of coppice-regenerated oak stems, it must be known how stems respond throughout the size distribution. Therefore, rather than examine the mean thinning response of all sprouts in this study, the largest 100, 150, 200, and 250 trees per acre were evaluated for each of the control and thinned plots at age 30. "Largest" was determined by dominant sprout height at age 5 and by dominant sprout dbh at age 30. Thus, an identical set of stems was not examined at both ages. However, because it is of interest to know how many of those sprouts originally selected as superior at age 5 maintained dominance at age 30 in each treatment, a "Dominance Index" (DI) was calculated. DI is defined as the percent of sprouts that were among the $n$ largest sprouts (100, 150, 200, or 250) per acre at age 5 as measured by height that were also among the $n$ largest sprouts per acre at age 30 as measured by dbh.

Average dbh and volume at age 30 were also examined on the $n$ largest stems. Gross cubic feet volume was estimated at age 30 using a local volume equation developed for University Forest from detailed measurements of 162 oak trees (Lowell unpubl.).

Lowell et al. (1987) have shown how the data for all sprouts could be used to develop equations to estimate the probability of "success" for a specified sprout diameter at age 30 given the height at age 5 of the sprout and the diameter of the parent stump. The form of the equations and signs of the coefficient estimates are:

$$\underline{p} = 1/(1+e^{(-(b0-b1*CRIT+b2*HT+b3*TRT*DIAM))}) \quad (1)$$

where $p$ is the probability that, given an initial (age 5) sprout height an individual stem will equal or exceed a given dbh (CRIT) at age 30,
CRIT is the predefined "success" criteria (inches),
HT is the sprout height at age 5 (feet),
TRT is 0 if the stand is not thinned and 1 if the stand is thinned, and
DIAM is the parent stump diameter (inches) measured 7 inches above ground.

The terms in equation (1) are presented in order of descending statistical significance. The most important term is the target diameter -- a larger desired future diameter (CRIT) decreases the probability of "success" (i.e., having a sprout that grows to at least that dbh by age 30). The next most important term is the height of the sprout at age 5 -- a relatively tall sprout has a better chance of achieving "success" than a shorter sprout. Finally, a larger parent-stump diameter provides a competitive advantage to a dominant sprout, but only if a clump thinning is conducted.

Note that because of the way the equations were fitted, a tree is considered "unsuccessful" at age 30 if it does not attain the specified dbh due to either slow growth or mortality. By graphing the probability of success for a sprout of given height against a range of success criteria, Lowell et al. (in prep.) developed a series of curves for use in making silvicultural recommendations for 5-year-old coppice-regenerated oak stands. These curves are reproduced here for red oak and white oaks on thinned and unthinned stands.

## RESULTS AND DISCUSSION

Regardless of the portion of the diameter distribution examined, early clump thinning at age 5 benefitted the selected sprouts -- i.e., sprouts that have expressed dominance by age 5 (Table 1). Moreover, the benefit provided by thinning, rather than disappearing, was still prominent at age 30. It is also notable that the magnitude of the response of volume to thinning shows a tendency to increase -- from 2.9 to 4.0 cubic feet for 250 to 100 stems per acre, respectively -- in the larger portion of the diameter distribution. It is also evident that on a percentage basis, cubic foot volume responds more than dbh regardless of the portion of the diameter distribution examined.

The DI values show that, in both thinned and unthinned stands, sprouts identified as superior at age 5 tend to remain dominant at age 30 (Table 1). Thus, superior sprouts can be identified as early as age 5, and most of these sprouts will maintain their dominance, particularly if they are favored by thinning. However, even if sprouts identified as superior at age 5 are not favored by early clump thinning, the DI is still 60 or greater -- i.e., 60% of those sprouts achieving early dominance maintained their dominance to age 30. Apparently, the intra-stump competition present on unthinned stumps is not sufficient to cause a complete suppression of the dominance achieved by superior sprouts at age 5.

To use these findings, it is necessary for forest managers to be able to evaluate the effect of a potential clump thinning on their stands. Figure 1 provides methodology which can be used to develop silvicultural recommendations for these oak stands. The horizontal axis indicates the desired average <u>minimum</u> (not mean) dbh desired in a particular <u>stand</u> at age 30. The five curves on each of the four figures are representative of different average dominant sprout heights at age 5, and the vertical axis, labeled "Probability of Success," provides an estimate of the probability of achieving a desired set of stand conditions at age 30 given the initial (age 5) average dominant sprout height. Another way of viewing this is that *p* estimates the proportion of sprouts which achieve or exceed the desired dbh.

Table 1.--Average diameter and volume for selected portions of the diameter distribution.

| | Largest *n* stems per acre | | | |
|---|---|---|---|---|
| | 100 | 150 | 200 | 250 |
| <u>Dbh (inches)</u> [1/] | | | | |
| Control | 7.6a | 6.9a | 6.0a | 5.6a |
| Thinned | 9.2b | 8.5b | 7.8b | 7.2b |
| Increase(%) | 21 | 23 | 28 | 29 |
| <u>Volume (cubic feet)</u> | | | | |
| Control | 9.5a | 7.8a | 6.2a | 5.3a |
| Thinned | 13.5b | 11.6b | 9.8b | 8.2b |
| Increase(%) | 53 | 49 | 58 | 55 |
| <u>Dominance Index (%)</u> [2/] | | | | |
| Control | 60 | 62 | 63 | 67 |
| Thinned | 69 | 74 | 79 | 78 |

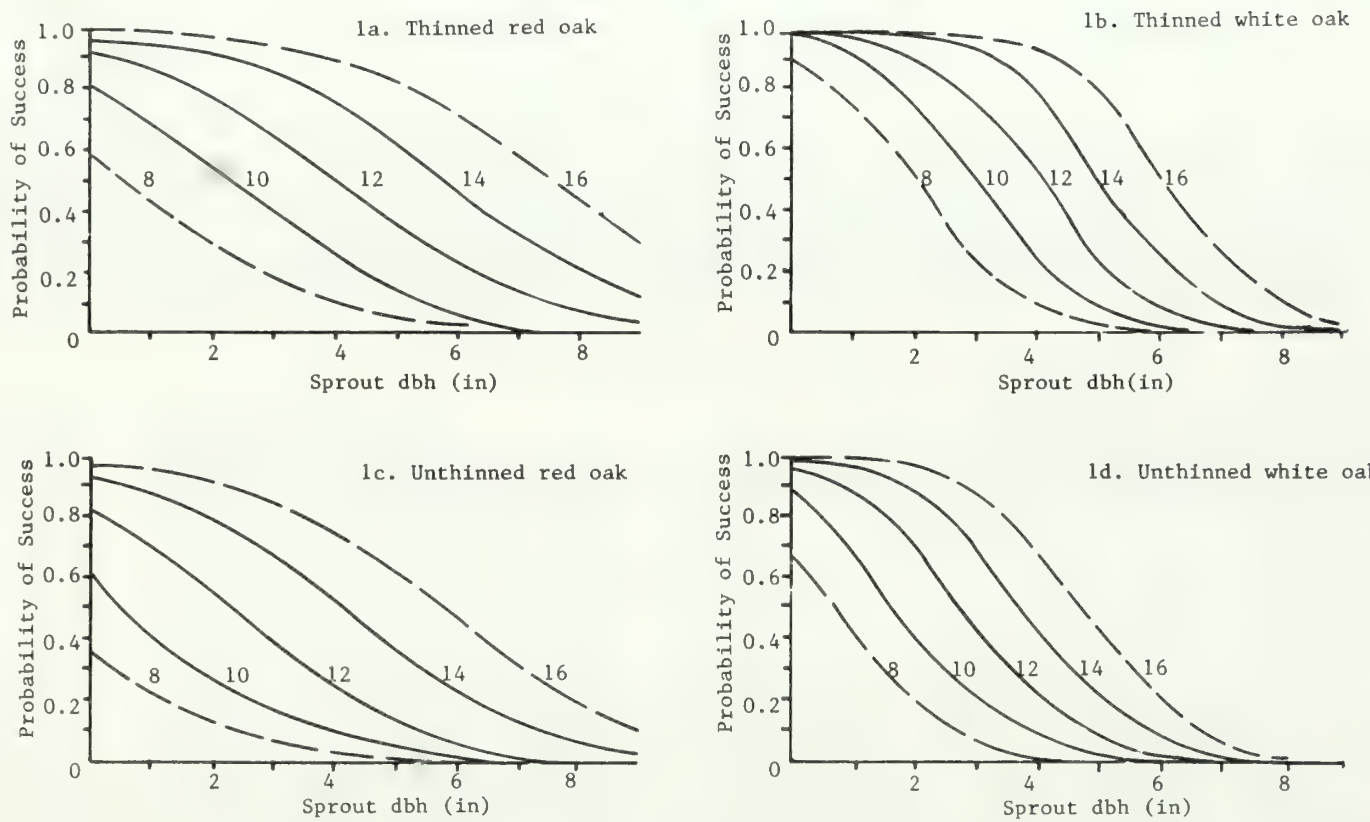
[1/] Within a parameter, measurements followed by the same letter are not significantly different at the 99% confidence level. Dominance Index was not tested for significant difference.

[2/] Dominance Index is the percent of stems among the largest *n* trees at age 5 by sprout height, and also among the largest *n* trees by dbh at age 30.

To utilize the curves in Figure 1, an inventory of coppice-regeneration must be conducted. A sample of sprouting stumps must be selected and the height of the dominant sprout on each stump recorded. The number of sprouting clumps per acre must also be estimated from this inventory. While no specific sample intensity is recommended here, the sample size must be large enough to provide a sample which the forest manager is confident is representative of the stand conditions. After this inventory is completed, the curves are used as illustrated in the following example.

Suppose that a stand of 5-year-old red oak stump sprouts is found to have an average dominant height of 10 feet and an estimated 500 sprouting stumps per acre. (In this study there were an average of 670 sprouting stumps per acre.) From Figure 1a the forest manager can determine that a clump thinning will produce a stand where the probability at age 30 of a 1)2.0 inch average minimum diameter is 0.53, 2)3.0 inch average minimum diameter is 0.38, and 3)4.0 inch average minimum diameter is 0.25. Viewed a different and perhaps more meaningful way, a clump thinning will produce a stand at age 30 in which 53% of the 500 dominant sprouts (265 per acre) will be at least 2 inches dbh, 30% (190 sprouts per acre) will be at least 3 inches dbh, and 25% (125 sprouts per

Figure 1. Curves used to evaluate the effectiveness of early clump thinning. (Values on curves are mean stand height (feet) at age 5.)



acre) will be at least 4 inches dbh. The intersection at 0.81 of the curve for 10 feet with the Y-axis also indicates that 81% of the original 500 dominant sprouts (405 per acre) will survive to age 30. These relationships, of course, are limited only to realistic stand densities.

The effectiveness of this clump thinning can be assessed by examining the projected future stand if no thinning occurs. Using the previous example for comparison, Fig. 1c shows that if a clump thinning is not conducted a stand will develop at age 30 in which 28% of the 500 dominant sprouts (140 per acre) will be at least 2.0 inches dbh, 17% (85 sprouts per acre) will be at least 3.0 inches dbh, and 10% (50 sprouts per acre) will be at least 4.0 inches dbh. Thus a clump thinning will produce a stand with 89% more stems -- 265 rather than 140 per acre -- which are at least 2.0 inches dbh compared to an unthinned stand, 124% more stems at least 3.0 inches dbh, and 150% more stems at least 4.0 inches dbh. Moreover, on the unthinned stand only 58% of the sprouts (290 stems per acre) can be expected to survive to age 30. Thus, in addition to the greater number of larger stems produced by the thinning, a forest manager will also have more stems to manage at age 30 thereby producing a greater number of management options than for an unthinned stand.

The different shapes of the curves in Figure 1 make it apparent that there are also species differences in growth potential. As the specified "success criteria" increases, the Probability of Success shows a tendency to be less for white oak than red oak implying that the growth of a given red oak sprout will exceed that of white oak. For example, in a thinned stand a 12 foot white oak sprout (age 5) has virtually no chance of reaching 7 inches dbh by age 30 whereas a similar red oak sprout has a 0.16 chance of achieving this dbh. Conversely, white oak sprouts have a better chance of survival than red oak sprouts. For example, in a thinned stand a 12 foot white oak sprout has almost a 100% chance of survival (dbh=0) compared to the 92% chance for a similar red oak sprout. Considering that the red oak and white oak species groups are composed primarily of scarlet oak, and white and post oak, respectively, these differences agree with the assessment that white and post oak tends to grow slowly and have intermediate shade tolerance, whereas scarlet oak grows rapidly and is relatively shade intolerant (Harlow and Harrar 1969).

In using these guides, there are two factors of which a user must be aware. First, not only is height at age 5 indicative of future "success", but also the diameter of the parent stump is significantly and positively correlated with "success", but in thinned stands only (see equation (1) and Lowell et al. 1987). Hence after a thinning operation, sprouts with relatively large parent stump diameters can be expected to outperform sprouts with smaller parent stump diameters. (Figures 1a and 1b were produced using the average parent stump diameter of 4.9 inches.) If a stand is not thinned, no competitive advantage results for a sprout with a relatively large parent stump diameter. This may be a consideration for managers who decide, for economics reasons, to thin only selected clumps in a coppice-regenerated stand. In such an operation, efforts should be concentrated on those clumps with relatively large parent stump diameters, provided that stump spacing will not cause excessive inter-stump competition in the future. Second, the limits of the original study must be kept in mind. The results presented apply to an average site wherein the treatment is a clump thinning and not a thinning to control the stand density. Estimates will vary with a better or poorer site and also if subsequent thinnings are used to control overall stand density.

## CONCLUSIONS

It is possible to identify superior sprouts as early as age 5 in stands of coppice-regenerated oak. Furthermore, if these superior sprouts are released at age 5 by a clump thinning, significant increases in dbh and volume will result. These increases (compared to dominant sprouts in unthinned clumps) will remain conspicuous 25 years after thinning. By using success probabilities, a forest manager can determine if, given the size and number of stems at age 5, a future stand with a desired minimum diameter can be obtained. Moreover, if stands are not thinned early, by the time they reach age 30 -- a point at which some researchers have recommended a first thinning -- existing growing stock will be inferior to that which would have existed if an early thinning had been conducted.

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# THE NEED TO IMPROVE MODELS FOR INDIVIDUAL TREE MORTALITY [1]

George Gertner[2]

ABSTRACT.--The primary source of variability in projections made with a widely used single tree growth and yield simulation model employed for modelling central hardwoods was shown to be due to the individual tree mortality model. It is suggested that the most efficient way to improve the predictive ability of the overall simulation model is to direct future research towards improving the individual tree mortality models through additional data collection and model restructuring.

## INTRODUCTION

Stand and Tree Evaluation Modeling System (Belcher et al. 1982), STEMS, is a single tree growth projection system that was developed by the USDA Forest Service to evaluate a wide variety of forest types in the Central States. A total of 3000 plots with 60000 trees were used to calibrate the Central States Version of the STEMS model. STEMS has primarily been used to evaluate management and silvicultural alternatives and for updating forest survey plots. The component models of STEMS are not strictly empirical, but are something in between empirical and mechanistic. The structure of the models are based on the calibration data, as well as the geometric and mechanistic properties that can be expected as a result of a long history of growth and yield research.

Gertner (1987 and 1988) used an error propagation method as a computationally efficient alternative to Monte Carlo methods to obtain estimates of precision of predictions made with a modified version of STEMS. Precision estimates for the STEMS model were desired to gauge the reliability and precision of predictions, to calculate confidence intervals, to statistically test hypotheses when experiments are performed with the model, and to weight projections used as an auxiliary source of information in combination with on-the-ground sample estimates.

Another use of the error propagation technique is for aiding in the development of future strategies for improving, in a systematic fashion, simulation models such as STEMS. Briefly described here is the method for doing this and suggestions for improving the STEMS model.

## ERROR BUDGET

The error propagation method provides a direct method for calculating the variance of predictions. For each function in the growth model, an approximation is used to approximate the variance of prediction made with the function when there is random error in the input of the function. By approximating the variance for each function, the random errors that pass from one function to another can be approximated and accounted for (Figure 1). With an iterative model such as a multi-year projection system, the initial errors entered into the functions of the model might be due to errors in the state variables. After the first iteration, the errors will be due to errors in predictions from past iterations. With each additional iteration, the variance will increase as errors propagate through the system. The final variance of the prediction for the overall system will be due to the accumulation of all the errors.

With the error propagation method, an error budget can be easily generated. An error budget shows the effects of individual errors and groups of errors on the accuracy of simulation projections. It can be considered to be a catalog of the contributions of the different error sources to the overall accuracy of the system. Some specific types of errors that might be considered when developing the error budget for a model are the following (Figure 1):

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[1]Paper presented at the Seventh Central Hardwood Conference, Southern Illinois University, Carbondale, Illinois, March 5-8, 1989.

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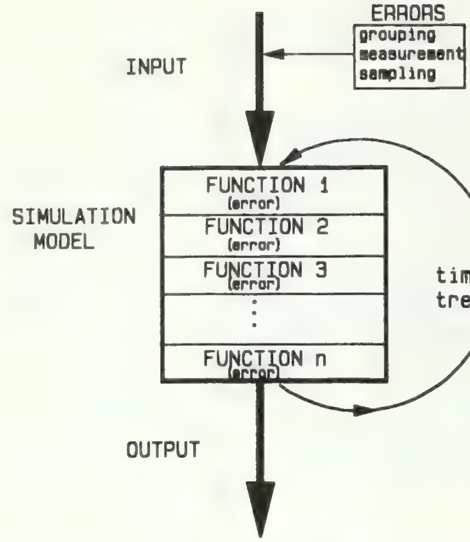


Figure 1.--Errors in simulation model.

1) Errors in measurements of state variables which are dependent on quality measurement equipment, time and budget constraints, etc.

2) Sampling errors when sampling methods are used to estimate the state variables. The errors are the result of taking only a subset of the total population when making estimates of the state variables. The size of the errors are dependent on sample size, plot size, sampling method, etc.

3) Process errors which refer to modelling errors and stochastic errors that are not accounted for by the component models.

4) Grouping errors which are due to grouping observations into classes (e.g., DBH classes). The grouping is a source of error.

Once an error budget is developed for a model, the important sources of error can be ranked in terms of their contribution to the variance of predicted forest characteristics. Based on the budget, future model refinement, experimentation and sampling can then be directed at reducing the more important sources of errors.

STEMS ERROR BUDGET (PROCESS ERRORS)

Currently, an error budget is being developed for the STEMS model. Presented here is the portion of the error budget due to process error which has been found to contribute a major proportion of the variability in projected forest growth.

The budget was developed by projecting 40 prism plots that were taken randomly from the oak-hickory (Quercus-Carya) component of Allerton Park. Allerton Park is a mixed hardwood forest owned by the University of Illinois.

The variance of predictions made with the overall simulation model were partitioned according to the important component models to generate the portion of the error budget due to process errors. The four major individual tree models used in the STEMS model are: 1) live crown ratio function, 2) annual diameter increment function, 3) probability of regular non-catastrophic mortality (survival) function, and 4) total stem volume function. The form of the models and the specification of process errors were as defined in Gertner (1987). A simplified flow chart of the projection system is shown in Figure 2. Sampling errors in the state variables that were used to initiate the system were that were used to initiate the system were accounted for and propagated through the models, but were not partitioned. It was assumed that there were no measurement errors in the state variables.

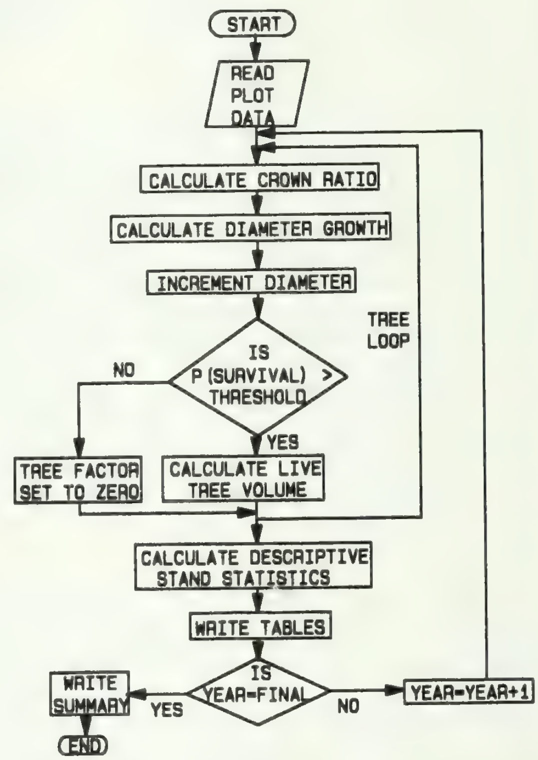


Figure 2.--Flow chart of modified STEMS projection system.

Table 1A shows the percent of variability in the number of trees per hectare versus time partitioned according to the four major individual growth models. As would be expected, almost one hundred percent of the variability in the number of trees per hectare is due to the mortality model. Other stand attributes were also greatly influenced by the mortality model. For example, shown in Table 1B is the partitioned variance for basal area per hectare. Although not as important, the mortality model is still the major source of variability in stand basal area.

Table 1A.--Percent of variability for number of trees per hectare associated with component models.

| Projection Year | Live Crown Ratio | Annual Diameter Increment | Mortality | Total Stem Volume |
|---|---|---|---|---|
| 0 | 0.12 | 0.53 | 99.35 | 0.0 |
| 10 | 0.11 | 0.43 | 99.46 | 0.0 |
| 20 | 0.09 | 0.34 | 99.57 | 0.0 |
| 30 | 0.08 | 0.28 | 99.64 | 0.0 |
| 40 | 0.04 | 0.27 | 99.69 | 0.0 |
| 50 | 0.02 | 0.25 | 99.73 | 0.0 |

Table 1B.--Percent of variability for basal area per hectare associated with component models.

| Projection Year | Live Crown Ratio | Annual Diameter Increment | Mortality | Total Stem Volume |
|---|---|---|---|---|
| 0 | 2.72 | 29.53 | 67.75 | 0.0 |
| 10 | 1.92 | 17.57 | 80.51 | 0.0 |
| 20 | 1.55 | 11.73 | 86.72 | 0.0 |
| 30 | 1.23 | 8.72 | 90.05 | 0.0 |
| 40 | 1.01 | 6.98 | 92.01 | 0.0 |
| 50 | 0.92 | 5.69 | 93.39 | 0.0 |

The results presented are not unique to the particular data set. Similar results were obtained with projections made for other stands and county wide inventories from locations in both Illinois and Wisconsin.

## FUTURE RESEARCH

Currently, the model used to predict the probability of annual mortality is a logistic model used in its stochastic form that overwhelms all other component models in the STEMS system. It is fairly well known that the art of modeling individual tree mortality is very poor (i.e., Buchman et al. 1983; Hamilton 1986 and 1980). With the error propagation method, the significance of not being able to model mortality precisely becomes apparent.

Based on the results presented here, future research should now be directed toward improving the ability to predict regular mortality. Even a marginal improvement in the mortality model would lead to a significant improvement in the precision of predictions made with the overall STEMS model.

There are a number of different approaches that might be taken to improve the mortality model. Some possibilities are as follows:

1) The collection of new data to supplement existing data, via samples or experiments, should be considered for improving the logistic model. Currently the data collected for the mortality model is deficient because the range of predictor variables is limited due to clustering and previous long-term experiments not being designed for the purpose of calibrating a logistic mortality model.

2) The inputs used for the mortality model are those that are typically collected in mensurational surveys. These variables might not be adequate for the purpose of modeling mortality. More detailed measurements, including the measurement of physiological variables, would potentially improve the precision of the logistic model.

3) Although STEMS is not a process model, consideration should be given to developing a mechanistic mortality model. If this is done, the goal should be to understand the physiological process of non-catastrophic tree mortality so that a deterministic mortality model can be developed.

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COMPETITIVE ABILITY AND GROWTH ALLOCATION OF PLANTED

NORTHERN RED OAK AND YELLOW-POPLAR SEEDLINGS[1]

T. E. Kolb and K. C. Steiner[2]

Abstract. -- Growth rate and growth allocation among organs of planted one-year-old northern red oak (Quercus rubra L.) seedlings were compared with those of a putatively more competitive tree species, yellow-poplar (Liriodendron tulipifera L.), in the presence and absence of interference with roots of Kentucky bluegrass (Poa pratensis L.). Seedling total dry weight, dry mass relative growth rate, and partitioning of weight to leaves, stems, and roots were measured periodically over a 173-day period. After 173 days, total dry weight for northern red oak was greater than for yellow-poplar in the absence of interference, while species did not differ in weight in the presence of interference despite a three-fold advantage in weight for seedlings of northern red oak when planted. Relative growth rate for yellow-poplar in both the presence and absence of interference was greater than that for northern red oak, indicating greater competitive ability for yellow-poplar. Yellow-poplar allocated more dry weight to leaves and stems and less to roots than northern red oak in the presence and, to a lesser extent, in the absence of interference. Northern red oak significantly increased growth allocation to roots at the expense of stems and leaves in response to interference, while allocation for yellow-poplar did not change. Species differences in growth allocation did not explain yellow-poplar's greater competitive ability under conditions of grass root interference.

Keywords: Quercus rubra L., Liriodendron tulipifera L., growth analysis, morphological plasticity.

## INTRODUCTION

A major concern in the management of northern red oak (Quercus rubra L.) is the difficulty encountered in regenerating new stands to replace those that are harvested (Crowe 1988, Holt and Fisher 1979). Efforts at artificial regeneration of northern red oak often fail because seedlings are unable to outgrow competing vegetation (Erdmann 1967, Farmer 1981, Foster and Farmer 1970, Hilt 1977, Russell 1973). Artificial regeneration of yellow-poplar (Liriodendron tulipifera L.) typically is more successful than that for northern red oak on sites dominated by herbaceous plants (Bowersox and McCormick 1987, Farmer 1981, Torbert et al. 1985), suggesting yellow-poplar has greater competitive ability under these conditions.

Competitive ability is defined as the capacity of a plant to capture resources under conditions where other plants limit resource levels. Differences in competitive ability exist among plants, but it is unclear which growth characteristics influence competitive ability. Characteristics that may be important include how growth is distributed among plant organs, and plasticity in growth allocation in response to competition (Grime 1979, Roush and Radosevich 1985). This study compares growth and plasticity characteristics of northern red oak and yellow-poplar seedlings when planted with grass root interference. The primary objective is to identify differences in growth allocation between these species which may explain the greater competitive ability of planted seedlings of yellow-poplar.

## METHODS AND MATERIALS

One-year-old seedlings of yellow-poplar and northern red oak from the state nursery were grown for 173 days in the presence and absence of a trimmed sod of Kentucky bluegrass (Poa pratensis L.). Seedlings and grass were grown outdoors (University Park, PA) in six wooden boxes (1.3m

[1]Paper presented at the Seventh Central Hardwood Forest Conference, Southern Illinois University, Carbondale, March 5-8, 1989.

[2]Research Assistant and Professor, respectively, School of Forest Resources, The Pennsylvania State University, University Park, PA.

length x 0.6m width x 0.6m depth) containing an agricultural top soil (Hagerstown series). Each box was partitioned into quarters by tempered masonite from the bottom surface to 20mm above the soil surface. A layer of pea-sized gravel supported by hardware cloth facilitated bottom drainage.

Treatments were assigned to each box using a split-plot design. On April 20, 1986, $0.30m^2$ of commercially produced bluegrass sod was planted in two quarters of each box (main plot), while the other two quarters were unsodded and subsequently kept free of weeds. On April 25, five seedlings of northern red oak or yellow-poplar ($26.9/m^2$) were planted in each box quarter (subplot). Prior to planting, the shoot of each seedling was trimmed to the same length as the taproot to standardize shoot-root ratios within each species.

Ten randomly selected seedlings of each species were destructively sampled at the time of planting to determine initial total dry weight and shoot-root ratio. Average total dry weights at time of planting were 3.8g for northern red oak and 1.2g for yellow-poplar. Average shoot-root ratios (based on dry weight) at the time of planting were 0.3 for northern red oak and 0.9 for yellow-poplar.

Soil moisture was maintained near field capacity by irrigation until initiation of stem elongation for all seedlings (27 days after planting). Thereafter, soil moisture was monitored every other day at a depth of 0.3m in grass plots with a Mark III Moisture Meter (Rick and Associates, Bellaire TX). Whenever an average reading of "1.5" (1=very dry soil, 4=very moist soil) was recorded, 3.8 liters of water were applied to each subplot. Grass was frequently clipped so that leaves of seedlings were never shaded.

Leaf, stem, root, and total dry weights for each seedling were measured in six destructive harvests (one box/harvest) in intervals of approximately 26 days, beginning when all northern red oak seedlings had developed only one new stem flush (41 days after planting). At each harvest, leaves and stems were collected from each seedling in one randomly selected box, the box was dismantled, and roots were extracted by washing soil away. Leaf area for each seedling was measured with a Li-Cor LI-3000 leaf area meter. Organ dry weights were measured after drying for 24 hours (60°C for leaves, 100°C for roots and stems).

Seedling total dry mass relative growth rate for each subplot was calculated as the slope of the linear regression of logarithmic ($\log_e$) values of mean seedling total dry weight at each harvest on the number of days since planting as described by Hunt (1982). Leaf weight ratio, stem weight ratio, and root weight ratio were calculated for each seedling to compare allocation of weight between species. For each species, partitioning of total dry weight among organs at each level of grass root interference was measured by comparing parameters of the allometric equation $Y=aX^b$. Comparison of allometric equations between different-sized plants minimizes the influence of ontogenetic drift on partitioning of growth among organs, allowing interpretation of environmental effects on partitioning (Hunt 1978, Ledig and Perry 1966). The allometric coefficient ("b") describes the partitioning of growth between organ "Y" and another organ or the whole plant "X", and is a measure of the ratio of their relative growth rates.

Allometric equations were calculated separately for Y=leaf dry weight, Y=leaf area, Y=stem dry weight, and Y=root dry weight, where X=total plant dry weight; and for Y=shoot dry weight where X=root dry weight. Shoot dry weight equalled dry weights of leaves plus the stem. In all cases, the linear form of the equation ($\log(Y)=a + b \log(X)$) was used to stabilize error variances (Baskerville 1972, Zar 1968). For each species, individual tree data were pooled over all harvests for regression. Differences in the allometric coefficient "b" between levels of grass root interference were tested by a linear covariance model for homogeneity of regression equations (Neter and Wasserman 1974).

## RESULTS

Grass root interference reduced total dry weights of both species by the fourth harvest (day 99) (Fig. 1). In the absence of interfer-

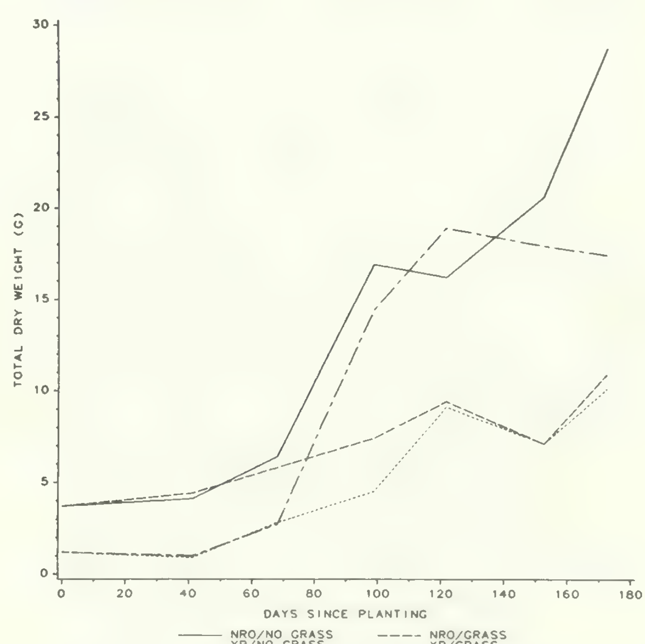


Figure 1.--Seedling dry weights for northern red oak (NRO) and yellow-poplar (YP) planted with and without grass root interference at seven harvest dates (days 0, 41, 68, 99, 122, 153, 173). Each value is the mean of five seedlings.

ence, average weight for northern red oak was greater than that for yellow-poplar at the first (day 0), second (day 41), third (day 68), and seventh harvest (day 173), while weights were similar between species at other harvests (days 99, 122, 153). In the presence of interference, average weight for northern red oak was greater than that for yellow-poplar at the first four harvests (days 0, 41, 68, 99), while weights were similar between species at the final three harvests (days 122, 153, 173). By the final harvest (day 173), seedlings of northern red oak averaged 2.2 new stem flushes in the absence of interference, and 1.2 new stem flushes in the presence of interference. Total dry mass relative growth rate for yellow-poplar was 54% greater than that for northern red oak in the absence of grass root interference (152 mg/g/week versus 99 mg/g/week), and 193% greater in the presence of interference (117 mg/g/week versus 40 mg/g/week).

For both species, increases in leaf weight ratio tended to coincide with decreases in root weight ratio in both the absence (Fig. 2) and presence (Fig. 3) of grass root interference. In the absence of interference (Fig. 2), northern red oak had greater root weight ratio and lower stem weight ratio than yellow-poplar at the first three harvests (days 0, 41, 68) and the last harvest (day 173), while differences were small at the other three harvests. Leaf weight ratio did not differ substantially between species at any harvest in the absence of interference. In the presence of interference (Fig. 3), northern red oak had greater root weight ratio, lower stem weight ratio, and lower leaf weight ratio than yellow-poplar at most harvests. The more consistent differences in growth allocation between species in the presence of interference can be attributed to the development of only 1.2 stem flushes by northern red oak in this environment versus 2.2 flushes in the absence of interference.

The shoot-root allometric coefficient for northern red oak in the absence of grass root interference was 0.97, indicating balanced allocation of growth between shoot and root (Table 1). The shoot-root coefficient decreased in the presence of interference (statistically

Table 1.--Allometric coefficients (b) of the equation log (Y)=a + b log (X) for northern red oak seedlings planted with and without grass root interference. Coefficients in the same column followed by the same letter are not significantly different at p<0.05.

| | X=root weight | X=total weight | | | |
|---|---|---|---|---|---|
| | Y | | | | |
| Environment | Shoot | Leaf | Leaf area | Stem | Root |
| No grass | $0.97^{a}$ | $1.22^{a}$ | $1.04^{a}$ | $0.93^{a}$ | $0.93^{a}$ |
| Grass | $0.66^{a}$ | $0.90^{a}$ | $0.64^{b}$ | $0.68^{b}$ | $1.10^{b}$ |

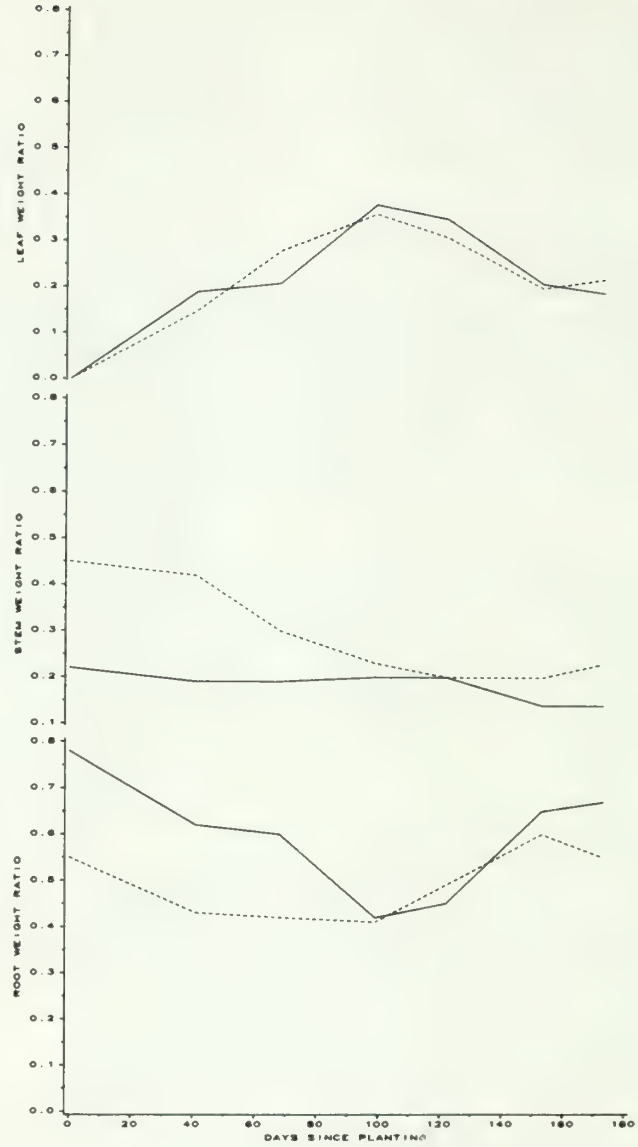


Figure 2.-- Leaf weight ratio, stem weight ratio, and root weight ratio for northern red oak (NRO) and yellow-poplar (YP) seedlings planted in the absence of grass root interference at seven harvest dates (days 0, 41, 68, 99, 122, 153, 173). Each value is the mean of five seedlings.

significant at p<0.09), suggesting a change in growth allocation. The effect of interference on growth allocation between shoot and root was the result of significant changes in allocation to all organs. Interference reduced growth allocation to leaves and stems, and increased allocation to roots.

Shoot-root allometric coefficients for yellow-poplar (Table 2) were identical at both levels of grass root interference (0.86), indicating similar growth allocation. Interference

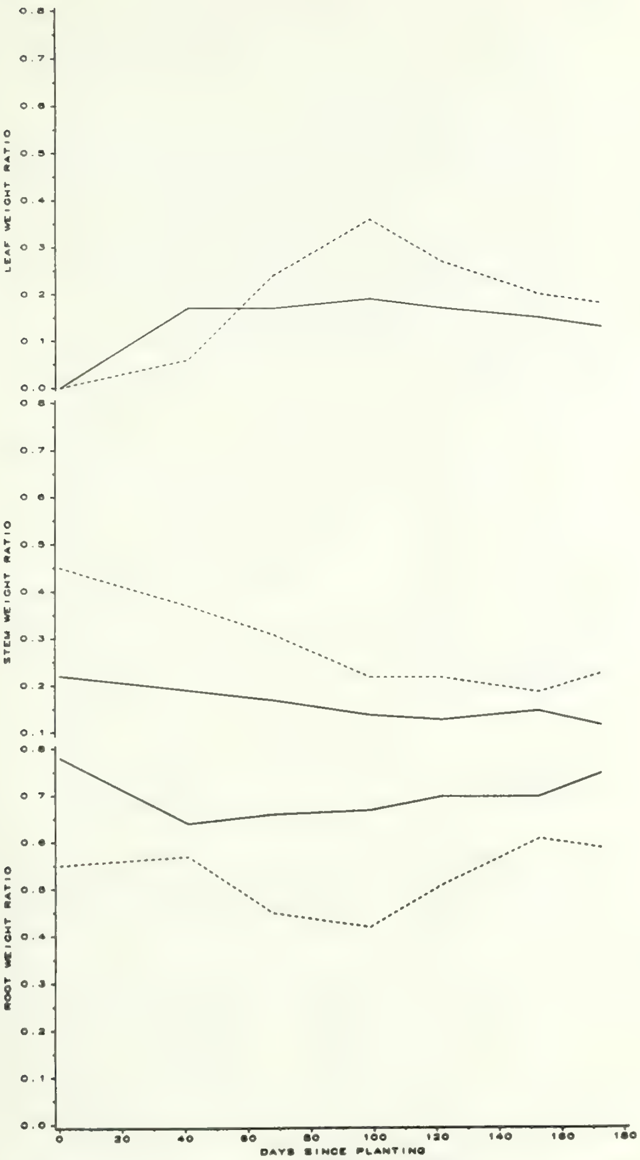


Figure 3.--Leaf weight ratio, stem weight ratio, and root weight ratio for northern red oak (NRO) and yellow-poplar (YP) seedlings planted in the presence of grass root interference at seven harvest dates (days 0, 41, 68, 99, 122, 153, 173). Each value is the mean of five seedlings.

had no significant effect on growth allocation to individual organs (Table 2).

DISCUSSION

Seedling total dry weights in the presence of grass root interference did not differ between northern red oak and yellow-poplar over the last three harvests of the growing season. This was despite a three-fold advantage in weight for northern red oak seedlings when planted. Yellow-poplar seedlings overcame the initial disadvantage in size due to a greater

Table 2.--Allometric coefficients (b) of the equation log (Y)=a + b log (X) for yellow-poplar seedlings planted with and without grass root interference. Coefficients in the same column followed by the same letter are not significantly different at $p<0.05$.

| | X=root weight | X=total weight | | | |
|---|---|---|---|---|---|
| | Y | | | | |
| Environment | Shoot | Leaf | Leaf area | Stem | Root |
| No grass | 0.86[a] | 1.16[a] | 1.04[a] | 0.80[a] | 1.07[a] |
| Grass | 0.86[a] | 1.49[a] | 1.36[a] | 0.76[a] | 1.04[a] |

relative growth rate compared to northern red oak. Thus, the competitive ability of yellow-poplar seedlings under conditions of grass root interference was greater than that for northern red oak. This is consistent with previous reports of the performance of planted seedlings of these species in field tests (Bowersox and McCormick 1987, Farmer 1981, Torbert et al. 1985).

Northern red oak and yellow-poplar differed both in growth allocation among organs, and in plasticity in growth allocation in response to grass root interference. In the presence of interference, northern red oak had more weight in roots and less in leaves and stems compared to yellow-poplar. Northern red oak increased growth allocation to roots at the expense of leaves and stems in response to interference, while yellow-poplar did not change growth allocation among organs. Northern red oak's determinate growth habit may account for its large increase in growth allocation to roots in response to interference. Root growth of oaks typically slows during stem elongation (Reich et al. 1980), and seedlings in non-grass plots developed more stem flushes (2.2) than those in grass plots (1.2). Of these differences in growth allocation, none adequately explain yellow-poplar's greater competitive ability in the presence of grass root interference, since water, and possibly soil nutrients were the only limiting resources. Grass foliage never shaded leaves of trees, and a preliminary study (Kolb 1988) indicated no detrimental allelopathic effects of Kentucky bluegrass foliage or roots on the growth of either species.

If all other factors were equal, northern red oak's greater root weight proportion and greater plasticity in growth allocation to roots should have increased its competitive ability against grass roots over that for yellow-poplar. That this was not the case suggests that yellow-poplar's root system is more efficient on a per weight basis in capturing resources than northern red oak's, perhaps due to differences in root structure or rates of water and nutrient absorption. Differences in dry weight allocation among roots, stems, and leaves between northern red oak and yellow-poplar may reflect adaptation

to different environments, since large allocation to root growth is a characteristic of plants found on nutrient-poor or droughty sites (Chapin 1980, Grime 1979, Orian and Solbrig 1977). It is possible that northern red oak's growth characteristics provide a longer-term ecological advantage that could not be observed in our short-term study.

## CONCLUSIONS

1) Competitive ability of yellow-poplar seedlings planted under conditions of grass root interference was greater than that for northern red oak over a 173-day growing season.

2) The competitive advantage of yellow-poplar seedlings under conditions of grass root interference was a product of high total dry mass relative growth rate sustained through continuous investments in leaf mass, but not through large investments in root mass or plastic allocation of mass in response to interference.

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# REGENERATION IN OAK STANDS FOLLOWING GYPSY MOTH DEFOLIATIONS[1]

David Allen and Todd Bowersox[2]

Abstract -- Regeneration was measured in oak stands where defoliation from gypsy moth had created understocked overstories. Abundance and species composition of ground vegetation present in gypsy moth created understocked sawtimber sized stands were determined for two physiographic regions in Pennsylvania. Average abundance for all commercially important species were similar for the two regions (about 28,500 stems/acre) and these species accounted for about 90% of all woody stems inventoried. However there were major physiographic differences in abundance values for specific species. In general: (a) red maple accounted for 90% of stems of commercially important species in the Allegheny Mountain region and 49% in the Ridge and Valley region; (b) birch was most abundant in the Ridge and Valley region, accounting for 29% of the stems of commercially important species whereas in the Allegheny Mountains region birch accounted for 4%; (c) red and white oaks accounted for 16% of the stems of commercially important species in the Ridge and Valley region and 4% in the Allegheny Mountains region.

## INTRODUCTION

Between 1969 and 1984, gypsy moth has caused moderate to heavy defoliation to about 6.2 million acres of forestland in Pennsylvania (Quimby 1984). A major moth outbreak in 1981 and below average growing season rainfall amounts from 1980 through 1983 have resulted in substantial tree mortality. Inventories of post-1982 mortality in these defoliated areas have been summarized by Quimby (1984). His study suggests that about 350,000 acres suffered approximately 30% volume loss and about 341,000 acres had greater than 50% volume loss. Most of the mortality was for oak and hickory species. Although stands in the moderate mortality class (15-30% mortality) are likely to regain a fully stocked stand characteristic and can continue to be managed as a unit, the stands with heavy mortality (>50% mortality) are likely to remain understocked until regenerated. Thus the future value of these heavy mortality stands will depend on the nature and characteristics of the post-mortality ground (understory) vegetation.

Numerous authors have summarized the state of knowledge for regenerating non-gypsy moth impacted stands in Pennsylvania (Penn State 1983). Generalized silvicultural guidelines have been developed for regenerating gypsy moth impacted Appalachian hardwood stands (Gottschalk 1988a and 1988b). Information on the composition and abundance of the ground vegetation in stands which have experienced heavy mortality (and possible salvage) have been limited to field observations. These field observations report the ground vegetation to range from "fern-grass savannahs" to "pokeberry-blackberry-blueberry thickets" to an occasional "best red maple-birch regeneration I have ever seen". At this point, we do not have quantitative information on enough stands to develop a point of reference for future cultural activities. Needed is a database on the abundance, composition and structure of ground vegetation in these heavily impacted stands so that forest resource managers can formulate revised plans, if needed.

Heavy mortality has occurred over a wide geographic area and for many edaphic-stand conditions. We selected two physiographic regions for the assessment of regeneration status after gypsy moth related mortality in Pennsylvania. The objective of the study was to determine the abundance and composition of the ground vegetation present in gypsy moth created understocked sawtimber sized stands growing in

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the Allegheny Mountains and Ridge and Valley physiographic regions.

## PROCEDURES

Oak dominated sawtimber sized stands that had understocked overstories from gypsy moth defoliation (>30% mortality, volume basis) were selected from Bureau of Forestry (Department of Environmental Resources, Pennsylvania) lands within a seven county area. Bureau of Forestry forestland managers provided guidance and documented that the selected stands were understocked due to gypsy moth related mortality. A total of 90 stands were designed to be selected with 45 located in the Allegheny Mountains physiographic region (Clearfield, Clinton and Centre Counties) and 45 located in the Ridge and Valley physiographic region (Huntingdon, Juniata, Mifflin and Perry Counties) (Figure 1). Within each physiographic region, 20 stands were designed to be selected in Site Productivity Class I, 15 stands in Site Productivity Class II and 10 stands in Site Productivity Class III. This sampling bias favoring the better sites was based on known site dependent regeneration relationships (Bowersox and Ward 1972, Gottschalk 1983) and forest management intensity. Site productivity classes were based on expected merchantable sawlog lengths for oak (Class I = 48 ft, Class II = 32 to 48 ft and Class III = < 32 ft; Bureau of Forestry procedures). Study stands met the designed number in each site productivity class except for the Class I sites in the Allegheny Mountains region where only 13 of the desired 20 stands could be located. Prior to gypsy moth defoliations, the mixed oak stands were even-aged and ranged from 80 to 120 years of age and were fully stocked.

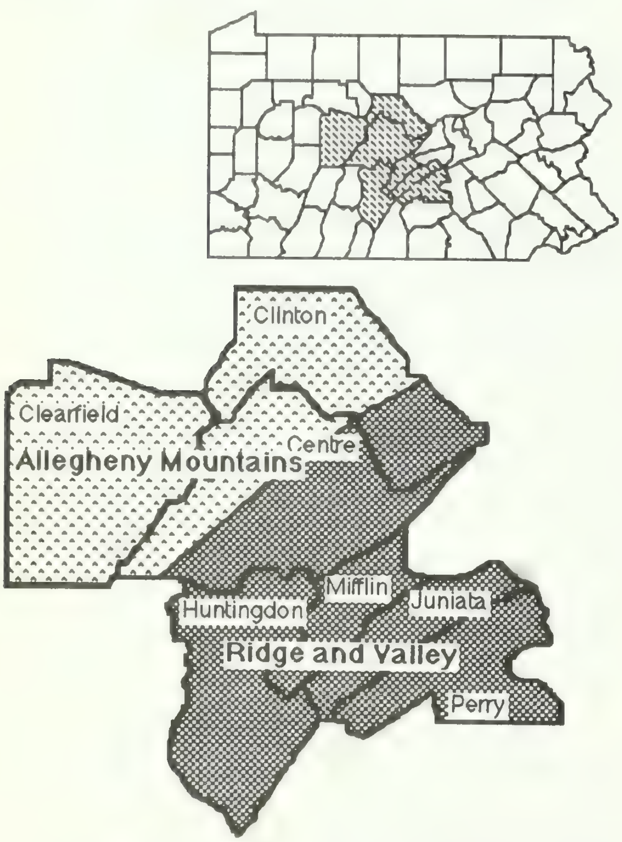


Figure 1. The central Pennsylvania study area and the counties located in the Allegheny Mountains and Ridge and Valley physiographic regions.

At each randomly located potential ground vegetation sample point, a field estimate of overstory stocking level was made to determine if the surrounding stand was below the B level for sample point acceptance. Residual live tree basal area for the ground vegetation inventory points ranged from 0 to 60 ft.$^2$ and averaged about 40 ft.$^2$, mainly oak species (Table 1).

Ground vegetation for six points in each stand were inventoried according to the procedures outlined by Marquis et al. (1984). Commercial and non-commercial species present 6 to 7 years after heavy mortality were inventoried for two height class. They were (a) 0.1-1.0 ft. and (b) >1.0 ft. height but less than 1.0 in. DBH. These inventory procedures also provide a basis for estimating non-woody vegetation and regeneration stocking criteria. Relative density of non-tree species was ocularly estimated, by 10% classes, for each species group and for collective ground cover dominance of each sample plot. The regeneration stocking criteria used (Marquis et al. 1984) required a decreasing number of seedlings with increasing seedling size for determining the likelihood of a 6 ft. radius (113.1 ft.$^2$) plot being stocked. These criteria required higher numbers of seedlings per size class than other regeneration stocking criteria (Sanders et al. 1976 and 1984) to insure success where deer browsing is severe. These criteria do not account for inter-species competition.

Statistical analysis was performed using Statistical Analysis System package programs (SAS 1985). The General Linear Models procedure was used for analysis of variance. Number of stems by species for the individual inventory plots were converted to a per acre basis, and used in the analysis. Sums of squares for stand nested within site productivity class was used as the error term for analysis of variance. If analysis of variance showed statistically significant differences attributable to region or site, means were separated by the Waller Duncan procedure. The 0.05 level of probability was accepted as significant.

## RESULTS

Total number of seedling stems averaged about 28,500 per acre for the commercial species and 3,800 per acre for the non-commercial

species. There were no significant differences between the two regions in the abundance of commercial species and non-commercial species for the 0.1 to 1.0 ft. and total height classes (Table 2). However, the Ridge and Valley region had significantly greater abundance values in the >1.0 ft. class for both species groups. The main reason for the regional difference in the large size class was the abundance values for birch and stripped maple (Table 2).

Red maple dominated the commercial species abundance values in both regions with a total of 13,563 and 25,895 stems per acre in the Ridge and Valley and Allegheny Mountains regions, respectively. The abundance values for total stems (above), and the 0.1 - 1.0 ft. stems (10,954 and 22,743 per acre for the Ridge and Valley and the Allegheny Mountains, respectively) were significantly different (Table 2). The regional difference in the >1.0 ft. red maple stems between the 2,609 per acre in the Ridge and Valley and the 3,152 per acre in the Allegheny Mountains was not significant. Red maple was most dominant in the Allegheny Mountains region, accounting for 90% of all commercial species stems. In the Ridge and Valley region, red maple accounted for 49% of all commercial species stems.

Species specific abundance values for birch, red oak and white oak were greater in the Ridge and Valley region than in the Allegheny Mountains region. The differences were significant for all size classes of white oak, the 0.1 - 1.0 ft. class of red oak and the >1.0 ft. class of birch (Table 2). The abundance value for ash, black cherry, yellow-poplar and other commercial species were not analyzed because of the low abundance values and infrequent occurrence.

Abundance values of non-commercial species were low in both regions, collectively accounting for about 12% of the average total woody stems in each region (Table 2). Sassafras with 1,776 stems per acre was the most abundant non-commercial species in the Allegheny Mountains region; and stripped maple with 1,964 stems per acre was the most abundant species in the Ridge and Valley region. Although the abundance of non-commercial stems was low in comparison to the total woody stems, these non-commercial stems may have an impact on commercial species diversity. Individually, two of the three non-commercial species in the Allegheny Mountains region had abundance values equal to or greater than the abundance values for red oak, white oak and other commercial species. Collectively, the non-commercial total abundance of 3,530 stems per acre was greater than all commercial species less red maple (3,038 stems/acre). In the Ridge and Valley region, the abundance value for stripped maple was greater than the values for red oak and other commercial

Table 1. Average overstory basal area in the sample stands for the two physiographic regions, by site productivity classes[1] and species group.

| Physiographic Region/County | Site Productivity Class[1] I | II | III | Weighted Average |
|---|---|---|---|---|
| | (- - - - - - | square feet | per acre - - - | - -) |
| Allegheny Mountains | | | | |
| Red oak | 20 | 15 | 11 | 16 |
| White oak | 5 | 14 | 19 | 12 |
| Red maple | 16 | 13 | 6 | 12 |
| Others | 4 | 2 | 3 | 2 |
| Total | 45 | 44 | 39 | 43 |
| Ridge and Valley | | | | |
| Red oak | 19 | 12 | 18 | 16 |
| White oak | 10 | 14 | 20 | 13 |
| Red maple | 5 | 3 | 2 | 4 |
| Others | 3 | 3 | 6 | 4 |
| Total | 37 | 32 | 46 | 37 |

[1] Site productivity classes were primarily based on expected merchantable saw log lengths, for oak I = 48 ft, II = 32 to 42 ft. and III = <32 ft.

Table 2. The average[1] abundance of species groups in the two physiographic region, by height class.

| Species Group | Height Class | Allegheny Mountains | Ridge and Valley |
|---|---|---|---|
| | (- - - - - - - - - - stems/acre | - - - - - - - - - - - ) | |
| Red oak | 0.1 - 1.0 | 530 a | 1,160 b |
| | > 1.0 | 177 a | 338 a |
| | Total | 707 a | 1,498 b |
| White oak | 0.1 - 1.0 | 397 a | 2,471 b |
| | > 1.0 | 61 a | 570 b |
| | Total | 458 a | 3,041 b |
| Red maple | 0.1 - 1.0 | 22,743 a | 10,954 b |
| | > 1.0 | 3,152 a | 2,609 a |
| | Total | 25,895 a | 13,563 b |
| Birch | 0.1 - 1.0 | 1,073 a | 2,590 a |
| | > 1.0 | 71 a | 5,396 b |
| | Total | 1,144 a | 7,986 b |
| Stripped maple | 0.1 - 1.0 | 39 a | 794 b |
| | > 1.0 | 103 a | 1,170 b |
| | Total | 142 a | 1,964 b |
| Witch-hazel | 0.1 - 1.0 | 466 a | 429 a |
| | > 1.0 | 199 a | 375 a |
| | Total | 665 a | 804 a |
| Sassafras | 0.1 - 1.0 | 1,192 a | 603 b |
| | > 1.0 | 584 a | 238 a |
| | Total | 1,776 a | 841 b |
| All[2] commercial | 0.1 - 1.0 | 25,239 a | 18,091 a |
| | > 1.0 | 3,694 a | 9,861 b |
| | Total | 28,933 a | 27,952 a |
| All non-[3] commercial | 0.1 - 1.0 | 2,476 a | 2,010 a |
| | > 1.0 | 1,064 a | 2,066 b |
| | Total | 3,530 a | 4,076 a |
| Total | 0.1 - 1.0 | 27,715 a | 20,101 a |
| | > 1.0 | 4,748 a | 11,909 b |
| | Total | 32,463 a | 32,000 a |

[1] Physiographic region means, within species and size class, with the same letter were not significantly different at the 0.05 level.

[2] Includes other commercial species not listed.

[3] Includes other non-commercial species not listed.

species. Collectively, the non-commercial species were more abundant than all commercial species, except birch and red maple.

Although the abundance values for all commercial, all non-commercial and all woody species did not differ between the two regions, the abundance values for individual species were greatly different between the two regions. Therefore, the abundance values among the three site productivity classes were analyzed by region. Physiographic region specific site productivity dependent differences in average abundance values (by size class) for individual commercial and non-commercial species were substantial. Differences between the lowest and highest average species specific abundance values among the site productivity classes were frequently greater than a factor of five. However, because of high variability in the database and non-constant error variance, site productivity class was a significant factor in

only five of the 25 analyses. The subjective methods for determining site productivity may have also weakened the analyses. Our analyses are continuing and at this time we can only present the following general trends.

Abundance values of all size classes of red oak, other commercial species, witch-hazel and stripped maple were greater in Site I stands than either Site II or III stands, regardless of region. White oak, red maple, birch and sassafras abundance values in response to site productivity class were dependent on region. Number of stems for all size classes of white oak were most abundant in the Site II stands in the Ridge and Valley region and in Site III stands in the Allegheny Mountains region. Greater white oak numbers on the Site II to III productivity classes may be due to chestnut oak accounting for 80% of all white oak stems. Red maple was most abundant in all size classes in Site I stands in the Ridge and Valley region; and in the Allegheny Mountains region, greatest abundance values for the 0.1-1.0 ft. size were measured on Site II stands and greatest values for >1.0 ft. size were measured in Site I stands. Number of stems for all size classes of birch were most abundant in Site I stands of the Allegheny Mountains region and in Site II stands of the Ridge and Valley region. Stems for all size classes of sassafras were most abundant in Site II stands of the Allegheny Mountains region and in Site I stands of the Ridge and Valley region.

The combined dominance of the surface area by all herbaceous and woody ground vegetation averaged 54% in the Allegheny Mountains region and 22% in the Ridge and Valley region. Over all site productivity classes, ferns were the dominant group in the Allegheny Mountains region (38% coverage) but not in the Ridge and Valley region (6% coverage). There was a tendency for ferns to be more dominant of the ground surface area in Site I stands than Site II or III stands (Table 3). Blueberry (and huckleberry) was the most dominant group in the Ridge and Valley region (21% coverage, overall) and second most dominant in the Allegheny Mountains region (14% coverage, overall). Blueberry group was more dominant in Site II and III stands than in Site I stands. Grasses, laurel, broadleaf weeds and others would occasionally dominate individual inventory plots but their overall coverage values were low (Table 3).

Over all site productivity classes, 72% of the plots in the Allegheny Mountains region and 83% of the plots in the Ridge and Valley region were stocked with commercial species (Figure 2).

Table 3. Relative amount of ground surface occupied by selected plant communities for the two physiographic regions, by site productivity class.

| Physiographic Region/Plant Community | Site Productivity Class I | II | III | Weighted Average |
|---|---|---|---|---|
| | (- - - % of surface area occupied - - -) | | | |
| Allegheny Mountains | | | | |
| Ferns | 48 | 32 | 35 | 38 |
| Blueberry | 8 | 11 | 28 | 14 |
| Grasses | 4 | 13 | 4 | 8 |
| Laurel | 1 | 4 | 9 | 4 |
| Broadleaves | 0 | 1 | 0 | 0 |
| Others[1] | 3 | 3 | 2 | 3 |
| Overall Dominance[2] | 55 | 48 | 62 | 54 |
| Ridge and Valley | | | | |
| Ferns | 9 | 5 | 1 | 6 |
| Blueberry | 14 | 27 | 26 | 21 |
| Grasses | 2 | 1 | 0 | 1 |
| Laurel | 0 | 1 | 6 | 2 |
| Broadleaves | 7 | 2 | 2 | 4 |
| Others[1] | 3 | 2 | 2 | 2 |
| Overall Dominance[2] | 20 | 19 | 29 | 22 |

[1] Include mosses, partridgeberry, strawberry, teaberry and vines.

[2] Overall Dominance - the relative amount of the stand surface area dominated by non-tree species. An independent assessment and not a summation of individual plant communities.

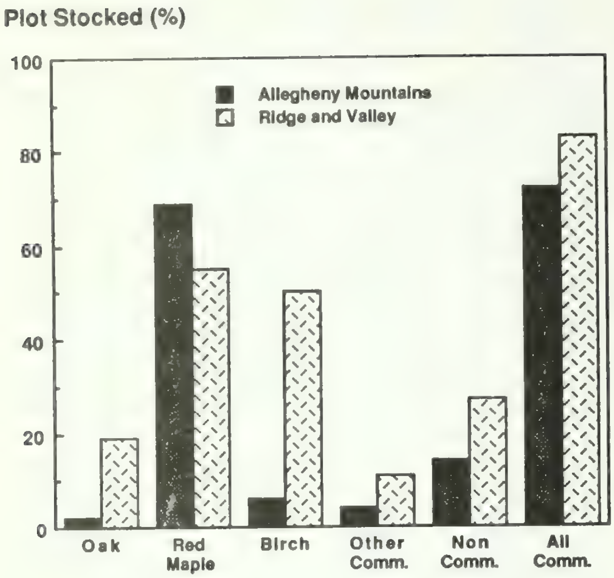


Figure 2. Percentage of plots stocked in the two physiographic regions by species group.

On an individual species basis, red maple was stocked on 69% of the plots in the Allegheny Mountains region, far greater than any other species group (Figure 2). Individual species stocking in the Ridge and Valley region was highest for red maple (55%) and birch (50%). Plots stocked with oak (19%), other commercial (11%) and non-commercial (27%) in the Ridge and Valley region were greater than the species specific values in the Allegheny Mountain region (Figure 2).

## DISCUSSION

Initial evaluations in sawtimber stands with heavy gypsy moth related mortality indicate that the stands were developing abundant and well distributed regeneration of commercial species. The regeneration was dominated by red maple in the Allegheny Mountains region and red maple and birch in the Ridge and Valley region. Red and white oaks were very sparse in the seedling component of the Allegheny Mountains region but accounted for about 16% of the commercial species seedlings in the Ridge and Valley region. Competing ground vegetation (particularly ferns) can restrict seedling establishment and growth (Bowersox and McCormick 1987, Kolb et al. 1989). In the oak stands of Pennsylvania, birch, red maple and stripped maple are the most frequent woody stems "observed" to tolerate fern dominated understories. Restricted mixtures of commercial species and greater fern domination of the understory appears to be more prevalent in the Allegheny Mountains region than in the Ridge and Valley region.

Seedling species compositions in the study stands were different from the overstory compositions. The extent of the composition shift caused by the gypsy moth could not be determined because pre-defoliation inventories were not available. Successful natural regeneration of oak species is a mystery throughout the range. In Pennsylvania, quantitative data on regeneration inventories from oak stands are limited to a few research reports. Bowersox and Ward (1972) inventoried 28 undisturbed mixed oak stands in the Ridge and Valley physiographic region and reported that number of woody stems per acre ranged from 2,667 to 79,000 and averaged 26,071. In their database, 5,985 of the stems were of commercial species comprised of 13% red oak, 33% white oak, 43% red maple, 2% birch and 9% other commercial species. Less intense inventories in three Ridge and Valley physiographic region stands that had received shelterwood treatments and then a clearcut found an average of 5,133 stems of commercial species with 6% red oak, 3% white oak, 74% red maple and 17% other commercial species (Bowersox and McCormick 1987). Ferns and grasses dominated the ground vegetation in both the shelterwood and clearcut status of these three stands. Comparatively, the gypsy moth disturbed stands had greater numbers of commercially important seedlings but with similar species composition as stands not disturbed by gypsy moth.

Forest managers desiring to increase the oak component in the developing regeneration need to consider the community differences of the two regions. In the Allegheny Mountains, oak abundance values were sparse and seedlings were smaller in relation to the red maple and non-commercial seedlings. Except in the fern and blueberry dominated unstocked areas, new oak seedling establishment and growth will depend on their ability to compete with the established red maple seedlings. In the Ridge and Valley region where species composition was more diverse, red and white oak was more abundant and seedlings were larger than in the Allegheny Mountains region. Oaks in the Ridge and Valley region accounted for 16% of the commercial species seedlings and were stocked on 19% of the plots. New oak seedling establishment, and growth of the new and existing oak seedlings in the Ridge and Valley region will depend on their ability to compete with birch, red maple and non-commercial seedlings. Knowledge is lacking on the ability of oak to become established and grow in competition with birch and red maple. Once this information is available, practices to increase the oak component can be recommended.

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# TREE MORTALITY FOLLOWING GYPSY MOTH DEFOLIATION IN SOUTHWESTERN PENNSYLVANIA[1]

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and

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Abstract.--Approximately 200 0.1-acre plots have been monitored in southwestern Pennsylvania since 1985 in order to measure the impact(s) of Gypsy moth (Lymantria dispar (L.)) defoliation on forest stands of the Appalachian Plateau. Plots were located in both defoliated and undefoliated stands. Average defoliation (in defoliated stands) was 33% in 1985, 50% in 1986, 19% in 1987 and 8% in 1988 and ranged from no defoliation on non-host species (e.g. yellow-poplar) to complete defoliation on many of the oaks. An average of 24% of the trees in defoliated stands had died as of July 1988. Defoliated stands lost an average of 34 square feet of basal area per acre. Thirty percent of the oak basal area was dead following defoliation. Mortality varied by species, aspect, site index and crown condition.

## INTRODUCTION

In recent years, the gypsy moth (Lymantria dispar (L.)) has extended its range into the Appalachian Plateau region of southwestern Pennsylvania. Gypsy moth defoliation often results in tree mortality. Mortality results from a combination of a reduction in photosynthetic capacity caused by leaf removal, a loss of root starch reserves during the refoliation process, stress induced during frost and drought periods, and secondary attack by the shoe-string root rot fungus (Armillaria mellea (Vahl.: Fr.)Kummer) and the two-lined chestnut borer (Agrilus bilineatus (Weber)) (Parker 1981, Wargo 1972 1977). Growth loss is a more subtle affect of defoliation that is often overshadowed by the more noticeable nature of mortality. Defoliation also opens the forest canopy during the growing season, drastically altering the understory environment. This opening of the canopy combined with selective tree mortality, reduction in acorn production, and the decrease in sprouting ability typical in defoliated stands, alters stand regeneration species composition.

Gypsy moth defoliation also substantially affects decisions made by natural resource managers and controllers of political purse strings. A 1984 damage survey conducted by the Pennsylvania Department of Environmental Resources of 691 000 acres demonstrates how severe tree mortality can be (Quimby 1987). Volume losses were 218 million cubic feet of pulpwood and 951 million board feet of

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sawtimber. The combined value of dead wood based on stumpage values current at the time of the study amounted to $104 million or approximately $151 per acre. Herrick and Gansner (1987) reported more conservative loss estimates in separate studies in central Pennsylvania and the Pocono Region of Pennsylvania. Median losses were approximately 6 percent (about 1 cord/acre) and median value losses were $4.40 and $3.50 per acre respectively. However, losses did reach 20 cords per acre and $50.00 per acre in some plots. Forest managers are frequently forced into salvaging stands to prevent losses of these magnitudes. Prevention of gypsy moth defoliation by aerial application of insecticide is also costly as evidenced by project costs reported by several states at the 1985 National Gypsy Moth Review in Columbus, Ohio (Table 1). Costs varied between $4.13 and $14.87 per acre. The average cost for the spray projects reported by Delaware, New Jersey, Pennsylvania, and West Virginia was $9.31 per acre. The total project costs for these four states in 1985 was approximately $3.4 million. As more acreage is defoliated by the gypsy moth, financial and human resources become limiting factors for suppression programs. Then it becomes imperative that priorities be made as to which forest areas can be treated. The highest priority will be high-value stands where the insect is a pest to the citizenry, such as residentia areas, campgrounds and scenic vistas. This is likely to leave few resources for the protection of uninhabited forest land. Therefore, treatment should be considered only for those stands that are both high-value and at a high risk of tree mortality. It is hoped that the information collected in this study can be useful in determining the relative risk of different stands. Presented here is a descriptive summary of defoliation and tree mortality in southwestern Pennsylvania.

Table 1. --Cost of the 1985 gypsy moth aerial spray programs in four selected eastern states.[1]

| State | Area Treated | Cost/Acre | Total Cost |
|---|---|---|---|
| | (Acres) | ($)[2] | |
| DE | 67 000+ | 7.47 | 502 000 |
| NJ | 39 922 | 8.97[3] | 358 100 |
| PA | 29 722 | 14.87 | 441 966 |
| | 70 882 | 11.73 | 830 742 |
| | 102 217 | 10.09 | 1 031 369 |
| WV | 54 020 | 4.13 | 223 102 |
| Total | | | 3 387 279 |

[1] Data in this table is taken from information reported by each state in the Proceedings of the 1985 National Gypsy Moth Review, Columbus, Ohio, Nov. 18-21.

[2] In some cases, these values do not include the costs of survey, administration, or treatment of small special use areas.

[3] This value is an unweighted average of the high and low costs reported by New Jersey in the proceedings.

PROCEDURES

To assist resource managers in the Appalachian Plateau region in determining which stands are at a high risk, 237 0.1-acre circular plots were established in Cambria and Somerset counties in southwestern Pennsylvania (fig. 1). Plots were located in both defoliated and undefoliated stands. A stand was considered "defoliated" when more than half of the plots in the stand received greater than 50% defoliation. At the time of establishment (1985 & 1986), a variety of tree characteristics, site conditions, and understory information were recorded for each plot (Table 2). Site index is an average of site index values calculated from four dominant or codominant oak trees per plot whenever possible. Separate equations were used for the white oak group and the red oak group using equations developed by Wiant and Lamson (1986). Volume equations were

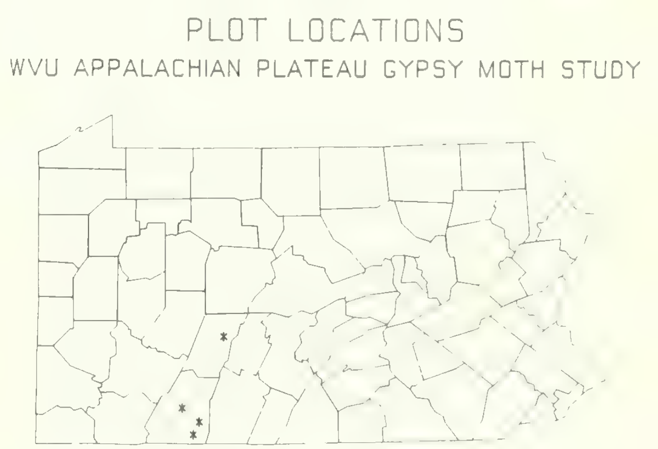


Figure 1.--Location of gypsy moth research plots established by West Virginia University in 1985 and 1986.

Table 2.--Data Collected - WVU Appalachian Plateau Gypsy Moth Study.

| Tree Characteristics | Site Conditions |
|---|---|
| DBH | Site Index |
| Total Height | SCS Soil Type |
| Merchantable Height (8" top) | Percent Slope |
| Species | Slope Position |
| Crown Class | Aspect |
| Crown Vigor | Understory Information |
| Defoliation | Species |
| Tree Grade | Height Class |

based on Wiant's (1986) formula for estimating form class 78 volume by International 1/4-inch rule. Tree grades were assigned using the dichotomous key published by Miller et.al. (1986). Since establishment, every plot has been revisited prior to defoliation each spring (mid May) to assess tree condition and again during peak defoliation each summer (late June through early July) to assess defoliation levels.

## STUDY AREA AND STAND CONDITIONS

The study was conducted on separate parcels managed by the Pennsylvania Game Commission, WESTVACO, and an individual landowner near the eastern border of the Appalachian Plateau in southwestern Pennsylvania. The topography of the plateau ranges from relatively flat to very steep in a short distance and elevations vary from 1300 to 2550 feet above mean sea level. The highest point in Pennsylvania, Mt. Davis, is near the Somerset county study areas. The dissected topography on the plateau forms a dendritic drainage pattern. As a result, aspect is important in determining species composition.

Forests of the plateau represent a boundary between the Mixed-Mesophytic forest described by E. Lucy Braun (1950) and a southern arm of the birch-beech-maple type of the Northern Hardwood forest (SAF 1980). Braun described the Mixed-Mesophytic forest as being dominated by American beech (Faqus grandifolia), tuliptree (Liriodendron tulipifera), basswood (Tilia heterophylla), sugar maple (Acer saccharum), chestnut (Castanea dentata), sweet buckeye (Aesculus octandra), northern red oak (Quercus rubra) borealis), white oak (Quercus alba), and eastern hemlock (Tsuga canadensis). Additional locally abundant species listed were black birch (Betula lenta), black cherry (Prunus serotina), cucumber tree (Magnolia acuminata), white ash (Fraxinus americana), and red maple (Acer rubrum). Sour gum (Nyssa sylvatica), black walnut (Juglans nigra), and species of hickory (especially Carya ovata and C. cordiformis) occur in a large proportion of the stands, but are never abundant. As Braun noted, there is a large number of dominants in this type, therefore composition and relative abundance vary greatly from place to place. There are few exceptions to Braun's description in the southwestern Pennsylvania gypsy moth sample. Of course American chestnut is restricted to the understory. Also basswood and sweet buckeye were essentially missing from the sample. Red maple and chestnut oak (Quercus prinus) were dominant species and black oak (Quercus velutina) and scarlet oak (Quercus coccinea) were locally abundant.

Pre-defoliation overstory composition in defoliated and undefoliated plots are compared in figure 2. Maple

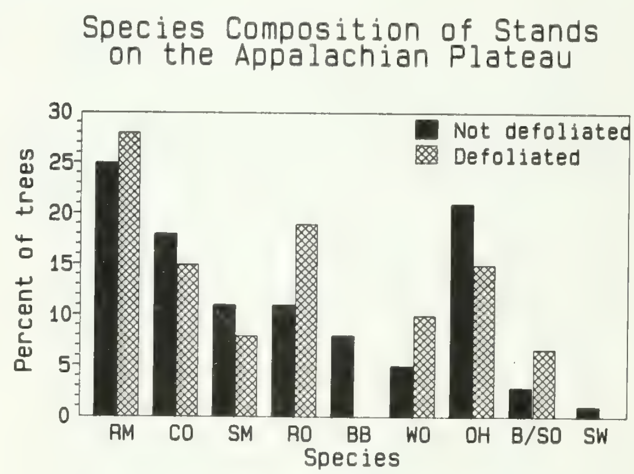


Figure 2.--Pre-defoliation overstory species composition of defoliated and undefoliated plots - WVU Appalachian Plateau gypsy moth study.

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* RM=Red Maple, CO=Chestnut Oak, SM=Sugar Maple, BB=Black Birch and Yellow Birch combined, WO=White Oak, OH=Other Hardwood and B/SO=Black/Scarlet Oak.

accounted for 36% of the trees in the sample in both cases. The defoliated plots had a larger oak component (51% vs. 37%). Undefoliated plots showed a decrease in northern red oak and white oak and an increase in sugar maple and black birch when compared to defoliated plots.

The sample includes the wide range of forest conditions found in southwestern Pennsylvania. The most noticeable difference between the defoliated and the undefoliated stands is the larger oak component and lower stand density (basal area/acre) in the defoliated stands (Table 3). Conditions were similar in a study in central Pennsylvania reported by Herrick and Gansner (1987).

Table 3.--Pre-defoliation stand conditions of defoliated and undefoliated stands - WVU Appalachian Plateau Gypsy Moth Study.

| | DEFOLIATED | | UNDEFOLIATED | |
|---|---|---|---|---|
| Variable | Mean | Range | Mean | Range |
| Ave. dbh (in) | 7.7 | 3-45 | 8.3 | 3-36 |
| Trees/ac (no.) | 266 | - | 266 | - |
| BA/ac (sq. ft.) | 118 | 40-259 | 140 | 82-199 |
| Stand age (yr.) | 78 | 49-140 | 74 | 46-111 |
| Site idx (Oak) | 53 | 32-91 | 60 | 40-81 |
| BA in Oak (%) | 74 | 10-100 | 57 | 12-100 |
| Vol/ac (bd ft:) | 8195 | 294-27518 | 8905 | 1977-21128 |
| Slope pct (%) | 23 | 0-58 | 21 | 0-46 |
| % Exposed Rock | 6 | 0-80 | 22 | 0-80 |

TREE DEFOLIATION

Gypsy moth defoliation in southwestern Pennsylvania has been sporadic since 1980. An attempt was made to sample stands just prior to initial defoliation based on egg mass counts, aerial sketch maps, and aerial photography. Since 1985, defoliation estimates have been made for every tree within 166 plots. Each estimate is the average of ocular estimates (20% classes) made by two independent observers. Figure 3 shows the average defoliation of the major species in 1986, the year of heaviest defoliation. These averages provide a relative susceptibility rating guide for the Appalachian Plateau in southwestern Pennsylvania. This guide is similar to the "general guide for gauging relative susceptibility (of species) in central Pennsylvania" published by Herrick and Gansner (1987).

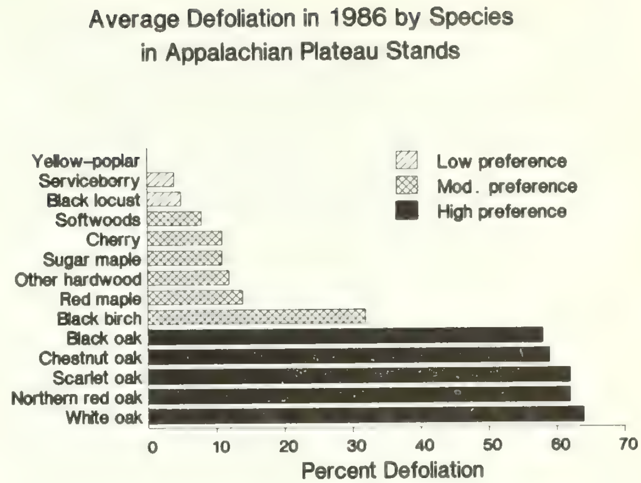


Figure 3.--Average individual tree defoliation by species in 1986 - WVU Appalachian Plateau Gypsy Moth Study.

As expected, the oaks suffered the brunt of the attack. The average oak defoliation was 62% or approximately the defoliation level often stated as the threshold for defoliation. Herrick and Gansner (1987) reported less severe defoliation on white oak (34%), northern red oak (41%), and scarlet oak (47%) in central Pennsylvania stands which were heavily defoliated in 1981. Though the initial stand conditions of both studies were similar, the central Pennsylvania stands were less severely defoliated (avg. = 39%) in 1981 (Herrick and Gansner 1987) than the southwestern Pennsylvania plots were in 1986. Results from our stands in southwestern Pennsylvania indicate that the oaks are all equally susceptible to defoliation (figure 3). Generally, black birch was in the intermediate or overtopped crown position underneath oak canopies. In 1986, black birch suffered an average defoliation of 32%. Defoliation was hardly noticeable on the remaining species.

STAND DEFOLIATION

Defoliation intensity and duration are key factors in assessing potential stand mortality. A stand was considered "defoliated" when more than half of the plots in the stand received greater than 50% defoliation. Mortality increased with increasing number of years of defoliation (Table 4.). The mortality rate sharply increases when a stand receives its second defoliation. However, in some cases a single defoliation resulted in

Table 4.--Tree mortality by defoliation history - WVU Appalachian Plateau Gypsy Moth Study.

| No. of Annual Defoliations | Mortality within Category (%) | Proportion of Sample (%) | Proportion of Total Mortality |
|---|---|---|---|
| 0 | 11 | 15 | 8 |
| 1 | 11 | 27 | 13 |
| 2 | 28 | 39 | 50 |
| 3 | 34 | 18 | 28 |
| 4 | 36 | < 1 | 1 |

substantial mortality.

A simple average percent defoliation for each stand is of limited value in assessing defoliation intensity because simple averages do not take into account differences in crown volume between trees. Therefore, defoliation was weighted by dbh squared as suggested by Herrick and Gansner (1986). Table 5 shows the severity of defoliation on the Appalachian Plateau plots since 1985. The heaviest defoliation was in 1985 and 1986. Even a few plots in the "undefoliated" control group were moderately defoliated in both years. This is because the defoliation category was based on a stand average and not on individual plot averages.

Table 5.--Weighted plot defoliation averages 1985-1988 - WVU Appalachian Plateau Gypsy Moth Study.

| | DEFOLIATED | | | UNDEFOLIATED | | |
|---|---|---|---|---|---|---|
| Year | N | Mean | Range | N | Mean | Range |
| 1985 | 99 | 32.99 | 0-99 | 21 | 7.36 | 0-36 |
| 1986 | 166 | 49.48 | 1-100 | 28 | 15.12 | 0-50 |
| 1987 | 166 | 19.40 | 0-74 | 28 | 6.86 | 0-33 |
| 1988 | 166 | 8.50 | 0-48 | 28 | 1.83 | 0-11 |

## TREE MORTALITY

As of July, 1988, twenty-four percent of the trees (3.0 inches dbh and larger) in the defoliated stands died compared with 11% in undefoliated areas (Table 6). Defoliated stands lost an average of 34 square feet of basal area per acre. Overall basal area losses increased by 15% due to defoliation. The oaks suffered most, losing 30% of their collective basal area.

The defoliated stands were separated into categories based on the proportion of oak relative to all other species (Table 7). The mortality rate increased sharply when oak made up more than 60% of the stand's basal area. In fact, when the oak component made up less than 60% of the stand, average losses were no greater than in undefoliated stands (Table 6 & Table 7).

Table 6.--Percent mortality in defoliated and undefoliated stands - WVU Appalachian Plateau Gypsy Moth Study.

| Species | DEFOL. | UNDEFOL. |
|---|---|---|
| All (% tree loss) | 24 | 11 |
| (% basal area loss) | 23 | 8 |
| Oak (% tree loss) | 39 | 16 |
| (% basal area loss) | 30 | 8 |

Table 7.--Percent tree loss in defoliated stands with different oak components - WVU Appalachian Plateau Gypsy Moth Study.

| % Oak | % Mortality | % Sample | % Total Mortality |
|---|---|---|---|
| < 10 | 0 | 0.5 | 0 |
| 11-20 | 2.5 | 2.5 | 0.5 |
| 31-40 | 11.0 | 5.0 | 2.5 |
| 41-50 | 8.0 | 5.5 | 2.0 |
| 51-60 | 9.0 | 6.5 | 2.5 |
| 61-70 | 15.5 | 10.0 | 6.5 |
| 71-80 | 21.0 | 16.5 | 14.0 |
| 81-90 | 21.0 | 26.5 | 24.0 |
| 91-100 | 43.0 | 27.0 | 48.0 |

Comparison of stem mortality for each oak species shows that scarlet, black, and chestnut oaks were particularly vulnerable with 57%, 46%, and 44% mortality respectively (Table 8). White oak and northern red oak fared a little better with 35% and 31% stem loss. It should be noted that scarlet and black oak represented a small proportion of the total sample, however even these small proportions represent 84 black oaks and 259 scarlet oaks. Red maple and sugar maple were included in the table in order to compare the oak mortality with species which were unaffected by the gypsy moth.

Mortality rates (Table 9) were lowest (15%) on the northeast and east aspects and on level sites where sugar maple, northern red oak and red maple dominated (i.e. made up the majority of the trees 3.0 inches dbh or larger). Where chestnut oak and red maple were the dominants (south and southeastern aspects) mortality

was the heaviest (30%). Mortality rates were intermediate on the remaining aspects (north, southwest, west and northwest) where red maple dominated with northern red oak or white oak.

Table 8.--Percent mortality for selected species in defoliated stands - WVU Appalachian Plateau Gypsy Moth Study.

| Species | %Species Mortality | %Sample | %Total Mortality |
|---|---|---|---|
| Scarlet Oak | 57 | 6 | 14 |
| Black Oak | 46 | 2 | 4 |
| Chestnut Oak | 44 | 18 | 31 |
| White Oak | 35 | 10 | 15 |
| N. Red Oak | 31 | 17 | 22 |
| Sugar Maple | 5 | 7 | 1 |
| Red Maple | 4 | 25 | 6 |

Table 9.--Percent mortality and species mixture on different aspects - WVU Appalachian Plateau Gypsy Moth Study.

| Aspect | Species Mixture | %Mortality |
|---|---|---|
| N | 33% RM-26% RO | 21 |
| NE | 23% SM-22% RO-19% RM | 12 |
| E | 30% SM-21% RO-14% RM | 14 |
| SE | 28% CO-24% RM-16% RO | 36 |
| S | 30% CO-24% RM-37% MO[1] | 34 |
| SW | 22% RM-22% WO-20% RO | 22 |
| W | 29% RM-16% RO-14% CO-14% WO | 28 |
| NW | 26% RM-24% RO-20% CO | 25 |
| FLAT | 30% SM-21% RO-14% WO-10% OH[2] | 13 |

[1] MO=about 10% each of white oak, northern red oak and scarlet oak.

[2] OH-other hardwoods.

Site index was grouped into three classes: 60, 60-70, and 70. Twenty-six percent of the trees on poor sites (SI < 60) died while only 16% died on average sites (SI 60-70) and 14% died on good (SI > 70) sites. Mortality was also greater on slopes steeper than 15% (28% loss) than on slopes which were less than 15% (15% loss). As with aspect, species is probably the overriding factor in these site/mortality relationships as the oak component was higher on the steep slopes and poor sites.

## MANAGEMENT IMPLICATIONS

Gypsy moth host preference classes were developed by Mosher (1915) and modified by Houston (1979). Oaks are considered high on the list of plant species "favored" by the gypsy moth; white oaks are considered particularly susceptible. Harrick and Gansner (1987) found that white oak in central Pennsylvania received only half of the defoliation that chestnut oak and black oak did. Based on the results of our study in the Appalachian Plateau (fig. 3), any of the oaks (northern red, black, scarlet, white, and chestnut) should be considered equally likely to be defoliated during a year of heavy defoliation such as 1986.

Even though the average defoliation of all the oak species was about 60%, scarlet, black and chestnut oak suffered heavier mortality than did white and northern red oak. This is not to say that the mortality of these latter two species was minimal by any means. Chestnut oak mortality accounted for almost one-third of the total mortality. This was a function of both the proportion of chestnut oak in the sample and chestnut oak's high mortality rate. When a stand's oak component exceeded about 60%, there was a substantial increase in tree mortality.

Mortality appears to be heavier on poor sites, steep slopes and some aspects largely because these sites support a large oak component. In the Appalachian Plateau of Pennsylvania, aspect seems to have such an influence on species composition that table 10 could be useful in establishing an initial hazard rating based on topographic maps in the absence of stand composition information. Though there are probably sites which do not fit the pattern in this table, the consistency of the relationship is surprising. Then results from a stand exam could be used in a final hazard rating.

Tree mortality due to insect defoliation is a complicated process involving interactions between trees, defoliators, secondary organisms and environmental factors. The most useful variables for predicting tree mortality following gypsy moth defoliation are defoliation duration, defoliation intensity and species composition. This paper provided summaries of this type of information for forest stands on the Appalachian Plateau of southwestern Pennsylvania. The next step is to determine what other variables might be useful in separating mortality differences within varying levels of defoliation and oak composition.

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Susceptibility Of Sugar Maple And Oak To Eleven

Foliar-Applied Herbicides

H.E. Garrett[1], M.W. Thomas[2] and S.G. Pallardy[3]

Abstract.--Eleven foliar-applied herbicides were tested for their effectiveness in controlling sugar maple and oak species. Picloram combined with 2,4-D (Tordon 101 M) applied at a rate of 757 ml/gallon of water proved to be the most effective. Three years after application, 100 percent of all sugar maple and 75 percent of all oak receiving this treatment were dead.

## INTRODUCTION

A significant increase in the density of sugar maple (*Acer saccharum* Marsh.) in Missouri's oak-hickory forests has been reported (Nigh *et al*. 1985; Pallardy *et al*., 1988). Similar increases have occurred in other states (Schlesinger, 1976; Cottam, 1949; Lorimer, 1984).

Sugar maple encroachment is considered undesirable because it is associated with the failure of oak to regenerate under its subcanopy. Oak regeneration in Missouri has steadily declined since logging in oak-hickory forests peaked between 1890 and 1920. Early oak regeneration failure was largely independent of the more recent encroachment of sugar maple, but has been exacerbated by it. Dense shade, caused from the overlapping crowns of sugar maple saplings, prevents adequate light penetration for oak seedling growth and development. Seed germination may occur but the young oak seedlings soon die for lack of light. Without advanced oak regeneration, there are no saplings present to assume canopy positions as mature oaks die or are harvested. The problem is especially relevant to mesic sites which have the greatest potential for growing high quality oak, as sugar maple appearance and dominance is most rapid on these sites (Pallardy et al., 1988). Because of the potential for serious decline in oak wood supply, a future negative effect on the hardwood forest products industry of the affected states is possible. Further, as more oak falls from a position of dominance in the overstory and is replaced by sugar maple, the mast-producing capacity of oak-hickory forests will be reduced. Loss of this important food source could be detrimental to wildlife populations, particularly those of deer, turkey and squirrel.

This study was an initial step in developing herbicide recommendations for sugar maple in Missouri. It was designed to test the effectiveness of a number of chemicals applied to the foliage with a backpack mist blower. Several oak species were also treated to document the effect of foliar-applied herbicides on oak.

## MATERIALS AND METHODS

Thirty-six, 0.02 ha (0.05 acre) circular plots were established on east-facing slopes at the Ashland Wildlife Area (Garrett and Cox, 1973) in late May and early June of 1984. The study employed a randomized complete block design with three replications of 12 plots each.

Thirty trees (15 sugar maple and 15 oak) were selected within each plot. Only trees that were healthy and growing vigorously were selected for treatment. There were 360 trees per replication or a total of 1080 trees, with 540 individuals each of sugar maple (*Acer saccharum* Marsh.) and oak species. Within the oak group, white (*Quercus alba* L.), chinquapin (*Quercus muehlenbergii* Engelm.), post (*Quercus stellata* Wangenh.), northern red (*Quercus rubra* L.), black (*Quercus velutina* Lam.) and blackjack (*Quercus marilandica* Muenchh.) oaks were included.

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The diameter of each tree was measured with Mishoto dial calipers calibrated to 0.02 mm accuracy. Seedlings less than 1.4 m (4.5') tall were measured approximately 15 cm (6") above the root collar. Saplings above 1.4 m (4.5') but less than 2.54 cm (1") in diameter were measured approximately 30 cm (12") above the root collar. Saplings over 2.54 cm (1") in diameter were measured at a height of 1.37 m (4.5').

Sugar maple study trees ranged from 3.54 to 117.24 mm (0.1-4.6") in diameter. The oak which grew under the subcanopy of sugar maple ranged from 2.22 to 117.34 mm (0.1-4.6") but averaged only 14 mm (0.6") bdh (basal diameter height) compared to 25 mm (1") dbh (diameter breast height) for the maple.

All herbicides were applied at label-recommended rates (Table 1); the highest rates were used when a range was provided. A Solo model 410 backpack mist blower mounted on an aluminum frame was used to apply all herbicides which were mixed the morning of application. Each of the 30 trees/plot was individually misted from at least two sides. Each tree was sprayed "to wet" but not to run-off. Replicate I was treated on May 21 and 22, replicate II on June 2 and 4 and replicate III over three days, June 11, 13 and 17, 1984. Defoliation data were recorded in September 1984, 1985 and 1986, one, two and three growing seasons after herbicide application, respectively.

Table 1.--Active ingredient(s) [AI] and application rate of herbicides applied to the foliage of sugar maple and oak.

| Product (Manufacturer) | AI | %AI | Rate (ml/gal) |
|---|---|---|---|
| Roundup (Monsanto) | Glyphosate | 41 | 79 |
| Banvel 720 (Velsicol) | Dicamba | 13 | 374 |
| | Related acids | 3 | |
| | 2,4-D | 25 | |
| Krenite (DuPont) | Fosamine ammonium | 42 | 76 |
| Tordon 101 M (Dow) | Picloram | 10 | 757 |
| | 2,4-D | 40 | |
| Garlon 3A (Dow) | Triclopyr | 44 | 123 |
| Garlon 4 (Dow) | Triclopyr | 62 | 95 |
| Weedone 2,4-DP (Union Carbide) | 2,4-DP | 60 | 38 |
| Weedone LV-4 (Union Carbide) | 2,4-D | 61 | 158 |
| Weedone 170 (Union Carbide) | 2,4-D | 30 | 57 |
| | 2,4-DP | 31 | |
| Weedar 64 (Union Carbide) | 2,4-D | 47 | 30 |
| Ethephon (Union Carbide) | Ethylene | 4 | 95 |

All trees were classified according to topkill and mortality. "Topkill" referred only to those study plants in which 100 percent defoliation had occurred at the time of observation, with no sprouting along the upper stem or in the crown. Topkill was used to quantify the first- and second-year observations. Study trees sprouting at the base were recorded separately and expressed as a percentage of the total plants treated. The term "mortality" was applied only to data collected in the third year after spraying, and was applied to those study plants that were 100 percent defoliated (topkilled) and showed no basal sprouting.

ANOVA was applied only to the third year (1986) mortality data as the 1984 and 1985 data were preliminary in nature. Treatment means were compared with least significant difference tests (LSD) at the 95% confidence level. Additionally, linear correlations between mortality and diameter of sugar maple were calculated.

## RESULTS

### Sugar Maple Control

Most herbicides proved ineffective in controlling sugar maple when mist blown (Table 2). In September of 1984, at the end of the first growing season in which herbicides were applied, only two herbicides (Tordon 101 M and Garlon 3A) provided 100% topkill in 80% or more of the study plants. Tordon 101 M gave the best control at 98%. Garlon 4 and Banvel 720 induced complete topkill of sugar maple in 76 and 67% of the study plants, respectively, while Roundup gave 47% topkill. The 2,4-D/2,4DP ester herbicides proved to be among the least effective in controlling sugar maple. The ester formulation of 2,4-D (Weedone LV-4) yielded the highest control of the group (44%), while the combination of 2,4-D and 2,4-DP ester (Weedone 170) yielded only 13% control. The ester formulation of 2,4-DP (Weedone 2,4-DP) also exhibited poor results, with only 9% of the study plants completely topkilled. The amine formulation of 2,4-D (Weedar 64) induced complete topkill in only 7% of the sugar maple study plants. Krenite and Ethephon were also very ineffective.

Table 2.--Percentage of plants showing topkill (1984 and 1985) and whole-plant mortality (1986) of sugar maple mist blown with eleven herbicides in May/June of 1984.

| Herbicide | Topkill 1984 | Topkill 1985 | Mortality 1986 |
|---|---|---|---|
| | Percent | | |
| Roundup | 47 | 36 | 36c[1] |
| Banvel 720 | 67 | 27 | 38c |
| Krenite | 7 | 24 | 29cd |
| Tordon 101 M | 98 | 100 | 100a |
| Garlon 3A | 80 | 42 | 40c |
| Garlon 4 | 76 | 40 | 60b |
| Weedone 2,4-DP | 9 | 11 | 16d |
| Weedone LV-4 | 44 | 20 | 22d |
| Weedone 170 | 13 | 16 | 18d |
| Weedar 64 | 7 | 7 | 7de |
| Ethephon | 2 | 4 | 9de |
| Control | 0 | 0 | 0e |

[1]Means with common letters are not significantly different at $P \leq 0.05$.

The resistance of sugar maple to most foliar-applied herbicides became even more evident in 1985 (Table 2). Most plants showed a reduced effect from the herbicide two growing seasons after application. Only one herbicide, Tordon 101 M, continued to provide good control, inducing or maintaining topkill in all sugar maple plants. Only two other herbicides (Garlon 3A and Garlon 4) provided at least 40% control. All other treatments proved much less effective by the second year after application.

Mortality percentages three growing seasons after herbicide application indicated that only Tordon 101 M provided 100% control (100% mortality) and was significantly more effective than all other herbicides tested. Most other herbicides yielded results similar to those reported in 1985, with the exception of Banvel 720 and Garlon 4. Application of both these herbicides resulted in improved control, although it was inadequate for a silvicultural prescription. Garlon 4 yielded the second highest level of control at 60% mortality.

Basal sprouting, for the most part, was not a problem in sugar maple. Most sprouts observed in 1985 (two growing seasons after application) had died by 1986. The two formulations of triclopyr (Garlon 3A [salt] and Garlon 4 [ester]) allowed the most sprouting -- 31% in 1985 and 19% in 1986. Krenite induced basal sprouting in 22% of the maple, while the remaining eight herbicides yielded sprouting of 11% or less.

## Control of Oak Species

Although the primary objective of this study was to evaluate the effectiveness of herbicides in controlling sugar maple, oak species were also included for testing. Most herbicides proved to be more effective in their capacity to topkill oak than sugar maple, but oak appeared to be the more prolific sprouter, although this was not tested statistically. One growing season after herbicide application, four treatments had resulted in topkill in more than 82% of the oak study plants (Table 3). Banvel 720 and Garlon 4 gave 89% control, Krenite 84% and Tordon 101 M 82%. The ester formulations of 2,4-D/2,4-DP provided intermediate control, with Weedone 2,4-DP and Weedone 170 inducing 78% and Weedone LV-4 67% complete defoliation. Garlon 3A and Roundup provided 73 and 64% topkill, respectively. Weedar 64 and Ethephon provided poor control.

Table 3.--Percentage of plants showing topkill (1984 and 1985) and whole-plant mortality (1986) of oak (all species) mist blown with eleven herbicides in May/June of 1984.

| Herbicide | Topkill 1984 | Topkill 1985 | Mortality 1986 |
|---|---|---|---|
| | Percent | | |
| Roundup | 64 | 58 | 38bc[1] |
| Banvel 720 | 89 | 47 | 58abc |
| Krenite | 84 | 69 | 67ab |
| Tordon 101 M | 82 | 62 | 71a |
| Garlon 3A | 73 | 47 | 53bc |
| Garlon 4 | 89 | 64 | 69ab |
| Weedone 2,4-DP | 78 | 40 | 45bc |
| Weedone LV-4 | 67 | 44 | 60abc |
| Weedone 170 | 78 | 42 | 60abc |
| Weedar 64 | 36 | 20 | 22cd |
| Ethephon | 11 | 4 | 11de |
| Control | 0 | 0 | 0e |

[1]Means with common letters are not significantly different at $P \leq 0.05$.

Data collected in 1985 revealed a reduction in effectiveness in every oak treatment, indicating that sprouting within the crowns was occurring. Only three treatments (Krenite [69%], Garlon 4 [64%] and Tordon 101 M [62%]) provided over 60% total defoliation in 1985.

As with sugar maple, changes in oak response data from 1984 to 1985 were much greater than between 1985 and 1986, indicating that the effects of the herbicides were stablizing and suggesting that first-year data in herbicide studies on woody vegetation may not be very

meaningful. In 1986, only Tordon 101M was found to result in mortality in excess of 70% (Table 3). However, Garlon 4 and Krenite yielded 69 and 67% mortality, respectively.

Basal sprouting was more prominent in oak than in sugar maple. In 1985, two treatments (Banvel 720 and Weedone 2,4-DP) resulted in basal sprouting in excess of 50%; two in over 40% (Weedone LV-4 and Weedone 170); two in over 30% (Garlon 3A and Weedar 64) and over 20% of Garlon 4 and Krenite-treated plants sprouted. Basal sprouting in 1986 was reduced for every herbicide except Roundup -- plants in four treatments sprouted in excess of 30% (Banvel 720, Weedone 2,4-DP, Roundup and Garlon 3A) and four induced between 20 and 30% plants with basal sprouts (Garlon 4, Weedone 170, Weedar 64 and Weedone LV-4).

The effectiveness of all herbicides on sugar maple, with the exception of Tordon 101 M (100% mortality), was significantly related to tree diameter ($r^2$ = 0.13 to 0.59). Significant regression slope coefficients indicated that larger diameter trees were more difficult to defoliate and, subsequently, harder to kill. Only three herbicide treatments, however, showed significant correlations between diameter and defoliation in oak ($r^2$ = 0.09 to 0.35). Defoliation with Roundup and the two triclopyr herbicides (Garlon 3A and Garlon 4) was significantly decreased as diameter increased.

## DISCUSSION AND CONCLUSIONS

The amine salt formulations of picloram combined with 2,4-D (Tordon 101 M), applied at a rate of 757 ml/gallon water by a backpack mist blower, proved to be the most effective treatment for controlling sugar maple. These results are consistent with those reported in the literature. Coble <u>et al</u>. (1969) found high percentages of red maple topkill when applying picloram in a similar manner. Seventy four percent topkill was achieved at a 0.5 lb aehg rate while 1.0 and 2.0 lb aehg both produced 100% topkill with no sprouting two growing seasons after application. Schwartzbeck and Wiltse (1964) in their work with sugar and red maple, also reported 98-100% control when applying picloram alone and in combination with four rates of 2,4-D. Nine percent of the maple sprouted at the base at the highest rate of application (0.7 lb picloram plus 2.0 lb 2,4-D aehg).

The two triclopyr-based herbicides proved to be marginally effective in controlling sugar maple, with Garlon 4 being the second most effective chemical. Sixty percent mortality was realized three years after application of the ester formulation of triclopyr in this study. Haywood (1980) reported 63% mortality and McCormack <u>et al</u>. (1981) reported 64 to 74% control after applying Garlon 4 to red maple. Lichy (1978) reported from 44 to 100% control. In contrast to results for Garlon 4, a significant reduction to only 40% mortality was observed in our work with the salt formulation (Garlon 3A). However, between 65 and 90% defoliation and 100% mortality have been reported by Lichy (1978) when Garlon 3A was applied to red maple. Perala (1980) reported only 20% topkill of sugar maple with one-half of the trees sprouting at the base. In view of the differences observed between our study and Lichy's, sugar maple may be more resistant to the triclopyr salt than red and some other maple species.

The phenoxy compounds composed of 2,4-D, and 2,4-DP alone and in combination were the least effective herbicides tested and hence cannot be recommended for herbicidal control of sugar maple. Maple has also been shown to be resistant to these compounds in other studies. Stewart (1974) reported only 30% topkill of vine maple one year after application of 2,4-D/2,4-DP in a water carrier and no mortality after three years. When using diesel fuel as a carrier, control was only slightly better. Lichy (1978) reported 50% topkill of red maple after misting 2,4-D (ester) and only 10% with the salt formulation. Between five and 58% topkill was reported by Coble <u>et al</u>. (1969) for red maple when the ester formulation of 2,4-D was applied.

Timing of herbicide application is extremely important. Most herbicides should be applied when the plants are actively growing to be effective, and this criterion was generally met in our study. One herbicide used, however, was designed to be applied in late summer and early fall. This compound, Krenite, is a contact herbicide and prevents bud and shoot development the following spring. The poor control of sugar maple with Krenite in this study (29%) may have, in part, been a result of the early spring application. Inconsistent results have been reported, however, when using Krenite to control striped and red maple, even with proper fall application (Sprague and McCormack, 1981).

Roundup and Banvel 720 both proved ineffective for controlling sugar maple. Ethephon, included to determine its effect as a defoliator, was also ineffective.

Oak species employed in this study, for the most part, existed beneath the dense shade of the sugar maple understory, a condition which may have influenced the vigor and consequently the results of this study. The basal diameters (bdh) of the oak were quite small, averaging only 14 mm (0.6").

Mortality and basal sprouting among treated oak trees were generally higher than for sugar maple. Tordon 101 M, the most effective herb-

icide on sugar maple, was also responsible for the greatest oak mortality. However, it was not significantly more effective than Garlon 4, Krenite, Weedone LV-4, Weedone 170 or Banvel 720 (Table 3).

While, in general, a negative correlation was found between diameter and herbicide effectiveness, Tordon 101 M was found to be equally effective on large and small diameter sugar maple plants. Trees up to 96 mm (3.8") dbh were killed by foliar application of Tordon. Perala (1980) demonstrated similar results. In a study of Tordon 101 M applied at a rate of 2.5 lb ae/ac, 73% topkill of sugar maple up to 3.8" dbh with only 4% basal sprouting was reported.

In view of the increasing prominence of sugar maple in Missouri oak-hickory forests and related future management problems, some method to control sugar maple is desirable. Our study demonstrates that of 11 chemicals tested, only Tordon 101M, induced sufficient mortality to be recommended for foliar application. Furthermore, it is noted that in herbicide trials of this nature, a minimum of two, and preferably three, years are desirable to secure reliable data.

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# DIRECT CONTROL OF INSECT DEFOLIATION IN OAK STANDS IS ECONOMICALLY FEASIBLE IN PREVENTING TIMBER VALUE LOSS[1]

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and

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Abstract.--We used data from 106 defoliated forest stands in West Virginia to establish the quantity of timber (board feet) that was lost due to mortality. Mortality was highest in stands with a large component of oak growing on better sites. Break-even benefit-cost analysis was used where avoidance of anticipated loss was the benefit and spray (chemical plus application) was the cost. Anticipated loss was computed as the product of mortality and stumpage value. We assumed that the stands would not be harvested for 20 years and that spraying would need to be repeated on either a 5-year or a 10-year cycle. We applied the benefit-cost analysis to 5 hypothetical cases, ranging from pure oak stands to stands with no oak component. For each case, timber value was determined using West Virginia (higher) and Maryland (lower) stumpage figures. Only in a case which had no oak was the break-even spray cost lower than actual spray costs that were reported to us. We conclude that if prevention of economic loss is the only consideration of a forest manager, except where oak is absent from the stands, spraying can generally be justified.

## INTRODUCTION

The commercial forests of the southern Appalachians are facing the advancing front of gypsy moth *Lymantria dispar* L.. To avoid excessive losses due to defoliation, landowners must make some important decisions. Basically, the landowner has three options: do nothing, harvest the timber, or implement a control strategy to prevent or at least minimize loss.

With the "do nothing" strategy landowners accept the risks in the hope that their stands will not be defoliated or that the defoliation is not severe enough to cause widespread mortality. Where timber is mature and there is an existing market, harvesting is an obvious solution.

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The final option is to implement some control strategy to prevent as much defoliation and damage as possible. Several different methods have been used over the years to attempt to control the gypsy moth. These include male moth trapping, sterile male release, the introduction of parasites and disease, silvicultural control, and the application of chemical pesticides.

The aerial application of chemical insecticides, specifically Dimilin, has provided some of the best results in controlling the gypsy moth (Nichols 1982) and was used in the analysis for this project.

This study uses mortality rates observed following insect defoliation in eastern West Virginia and western Maryland. Using economic analysis and given the expected mortality, we determined which stands we can afford to spray and retain profitability.

HOST SUSCEPTIBILITY AND VULNERABILITY

The susceptibility of a forest stand can be described as the probability that it will experience defoliation. It has been shown that a stand's susceptibility to defoliation depends largely on the species composition and the site and stand conditions such as aspect, slope position, and soil condition (McManus 1980).

Moser (1915) found that susceptibility was also affected by the stage of growth of the insect larvae. Some tree species were fed upon by all larval instars while others were preferentially eaten by certain instars.

Bess et al (1947) reported that the most susceptible stands in the northeast were those which grow on typically dry sites such as rocky ridges or deep sands. These highly susceptible stands have often been disturbed in some way. These disturbances include fire, ice, snow, or wind. The trees on these sites are often poorly formed, slow growing oaks which have structural features favorable to ovaposition by the gypsy moth. Structual features include deep bark fissures, bark flaps, and holes or wounds. Bess and coworkers also found susceptible stands to be open in nature and hosting understory plants such as blueberry, huckleberry, bracken fern, sweetfern, grasses, and sedges. Leaf litter in susceptible stands was shallow and exposed rocks and ledges were common. The forests in the northeast which were least likely to be defoliated were those that grow on well drained, loamy soils where soil moisture was not a limiting factor to growth. The sites were relatively undisturbed. Resistant stands were usually well stocked and contained a diversity of tree species. This species mixture may even include some which are highly preferred by the gypsy moth. The trees on the resistant sites were relatively fast growing and provided very few favorable structual features. The leaf litter in resistant stands was usually deep, thus providing habitat for gypsy moth preators. The understory species which were found to be prevalent in resistant stands include mapleleaf viburnum, woodland ferns, and wild sarsaparilla. Houston (1979), Houston and Valentine (1979), and Houston (1983) reported findings similar to those of Bess et.al. (1947).

In contrast to susceptibility, vulnerability refers to whether or not trees will die as a result of defoliation. Susceptibility and vulnerability are somewhat independent of one another. Houston (1983) reported that stands which were more susceptible were often less vulnerable because they were constantly stressed by the environment in which they grow and were acclimated to such conditions.

The amount of mortality that occurs after defoliation is related to such factors as the intensity of defoliation, the number of defoliations, the trees' condition before defoliation, the site and stand conditions such as aspect, slope percent, slope position, and environmental factors such as drought and late spring frosts before and after defoliation (Mason et. al. (1987).

Hicks and Fosbroke (1987), working in the Appalachian Plateau region of Pennsylvania, found that trees which were most vulnerable to mortality were oaks (especially white oaks), growing on steeper slopes, southwesterly aspects, and on sites with a higher site index.

In the Pocono Mountain Region of Pennsylvania, Gansner and Herrick (1984) found that oaks (especially white oaks), with poor crowns and low vigor, on poor growing sites and on westerly aspects were more likely to die.

Working in Pike and Monroe counties PA, Herrick et. al. (1979) found that stands that were more vulnerable to mortality were those in which the trees had poor crowns, were growing at higher elevations, had a greater distribution of grees 11 inches DBH or less, were composed of largely preferred species such as oaks, and were located on lower slope positions.

## PHYSIOLOGICAL EFFECTS OF DEFOLIATION ON TREES

Defoliation of a tree by insects causes the tree to be stressed. If the defoliation stress is severe or if it is coupled with other stresses the tree becomes predisposed to attack by secondary organisms. These secondary agents further stress the tree and often ultimately cause death.

Wargo (1978) reported that the degree to which a tree is affected by defoliation depends on several factors: the percentage of foliage eaten; how many successive years the tree was defoliated; what time of year the tree was defoliated; the weather conditions after defoliation; if secondary agents attacked the tree; and vigor of the tree before defoliation (Graham 1963, Acciavatti 1982).

The percentage of foliage which is eaten by any defoliator is very important in determining whether or not the tree can recover from defoliation. In any case, we can assign a probability of mortality to trees or stands and that probability is associated with the susceptibility, vulnerability and likelihood of epidemic-level insect populations.

### ECONOMIC ANALYSIS

With an insect such as gypsy moth which is invading the southern Appalachian region, imminence of defoliation can be forecast using available survey and detection. Therefore, an effective method to determine if control is economically feasible is important to the forest landowner.

Canham (1986) presented a break-even benefit cost analysis used to make sound forestry decisions. Future costs and revenues are discounted at a given interest rate to a present value. This value represents the minimum benefit required for a control project to at least break even. We utilized a procedure of this type in our study.

McCay and White (1973) conducted a similar study in which they calculated immediate losses and estimated future sawtimber losses from gypsy moth defoliation on a per acre basis. The future losses were discounted back to present values. The present value of the losses represents the amount of money the landowner could afford to pay for forest protection.

Another method for estimating the benefits of some control strategy has been presented by Gansner and Herrick (1987). Measurements were taken on plots in central Pennsylvania from 1978 to 1985. The percent loss in timber value and compound rate of change in value for all susceptible trees were calculated. The dollar values represented the standing trees' net value in the production of 4/4 inch lumber and/or pulpwood, allowing for the cost of conversion.

## METHODS

### STUDY AREAS

The data for this research were collected from two different study areas, Sleepy Creek Public Hunting and Fishing area in the eastern panhandle of West Virginia and Green Ridge State Forest in western Maryland (fig. 1).

Sleepy Creek Public Hunting and Fishing area, which is maintained by the West Virginia Division of Wildlife, is located on the Morgan-Berkeley county line in West Virginia and is about 6 miles southeast of Berkeley Springs and 11 miles west of Martinsburg. It is comprised of 23,000 acres of mountainous and rolling terrain consisting of mostly pine-oak and oak-hickory forest types. Sleepy Creek contains two mountains; Sleepy Creek Mountain and Third Hill, which range in elevation from 880 to 2,172 feet above sea level. The soils are shallow, shaley to stony loams with low moisture levels.

From 1981 to 1983 various areas of West Virginia's eastern panhandle received heavy defoliation. The looper complex which defoliated the areas in the eastern panhandle consisted mainly of *Phigalia titea* (Cramer). Other species which were involved included *P. strigateria* (Minot), *Erranis tiliaria* (Harris), and *Alsophilia pometaria* (Harris) (Butler 1985). Loopers have similar host preference and feeding season as gypsy moth, therefore we felt the looper data were applicable to gypsy moth.

### FIELD PROCEDURES

Field data was collected from 141 one-tenth acre plots. The plots were separated into those areas which according to reports had received 1, 2, or 3 years defoliation (106 plots) and control plots which received no defoliation (Crow 1985). Tree data which were collected on each plot included: tree number, azimuth from north, distance from plot center, species, dbh, crown vigor estimate, tree grade (trees 9.6 inches DBH and greater),

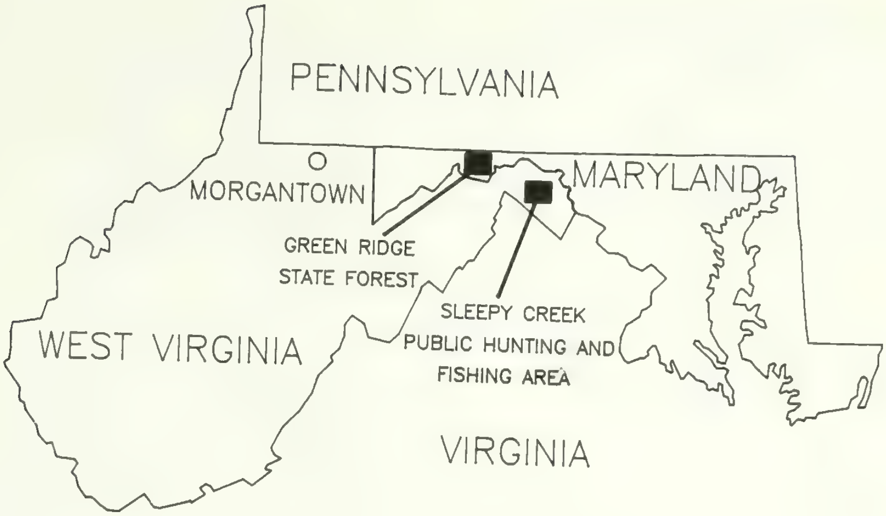


Figure 1.--Location of study sites.

crown class, merchantable height (to a 4 inch top), and total height. Plot data which were collected included: plot number, date, number of years defoliated, aspect, slope percentage, slope position, and an estimation of the percentage of exposed rock (Crow 1985).

Merchantable volume in board feet was calculated for each tree with a diameter breast height (dbh) of at least 10 inches and a tree grade of 1, 2, or 3.

Because original heights were taken to a 4 inch top, Wiant and Yandle's (1984) taper system formula for predicting tree merchantable height, given an 8-inch diameter limit, was used.

The tree's dbh and the calculated merchantable height was then used in volume equations produced by Wiant (1986) to predict the board foot volume for each tree. The equation for predicting International 1/4 inch volume (form class 78) was used in this analysis.

The volumes were then separated into live and dead categories for each species. The total volume, live volume, and dead volume for each species were accumulated for each plot.

ECONOMIC ANALYSIS PROCEDURES

Mortality ratios were developed by dividing the total dead volume for each species by the total volume (live and dead) for that species. For example, if red oak dead volume was 30 board feet and total red oak volume was 100 board feet then the mortality ratio would be 30/100 X 100 or 30%. This was done for each of the species or species group. The per acre volumes and the mortality ratios are shown in Table 1.

The average volume per acre for each species was multiplied by the mortality ratio for that species to calculate a volume loss per acre for the species. Stumpage values received from the West Virginia Department of Agriculture and the Maryland Forest Service for the areas in which the research plots were located were then applied to the volume losses for each species to derive a per acre value loss for each species. These loss values for each species were then summed to develop a total value loss per acre.

This total loss per acre is considered to be a benefit assuming that the landowner would spray and consequently the mortality loss would not occur. Other losses such as growth loss, aesthetic value loss, and recreational losses which could be incorporated into the benefit category if the gypsy moth was controlled by spray were not accounted for because of the difficulty in assessing an accurate value loss for each of these variables. Conversely, value loss was not adjusted for salvage value, presuming mortality occurred. Also stand operability for logging was not taken into consideration.

Several assumptions were made to complete the economic analysis. The first assumption was that the stand age is 60 years which is a reasonable average for many stands in the region. The second assumption was that the rotation age is 80 years. The 80 year rotation age was derived using Schnur's yield tables for upland oaks (Schnur 1937) to calculate the rotation age at which mean annual increment was maximum. The final

Table 1.--Dead and total volumes with mortality ratios for each species for the 106 defoliated plots.

| Species | Total Dead Bdft | Total Bdft | Dead Bdft Per Acre | Total Bdft Per Acre | Percent Mortality |
|---|---|---|---|---|---|
| Red Oak | 6391 | 19588 | 603 | 1848 | 33% |
| Misc Oak | 4197 | 40284 | 396 | 3800 | 10% |
| White Oak | 1742 | 17671 | 164 | 1667 | 10% |
| Chestnut Oak | 18897 | 32460 | 178 | 3062 | 58% |
| Hickory | 4455 | 6478 | 420 | 611 | 69% |
| Other | 357 | 6599 | 34 | 623 | 5% |
| Total | 36040 | ]23081 | 3400 | 11611 | 29% |

assumptions were that landowners will need to spray every 5 years or every 10 years until harvest.

After the value per acre loss or benefit was calculated for a stand, the cost of control was then calculated. Periodic spray costs which would occur in the future were discounted back to present values using 6 percent as the rate of return.

Benefits were then compared to costs; if the benefits were greater than costs, the implication is that the landowner could afford to spray. The benefit-cost analysis was calculated until a spray cost was found that made benefits and costs essentially equal. The point at which the benefits and costs are equal can be considered the break-even point.

The benefit-cost analysis was conducted on the actual losses by species groups that were experienced on the 106 defoliated research plots in West Virginia and Maryland. Stumpage values from West Virginia and Maryland were used to see how stumpage prices affect the break-even point. Maryland stumpage values were considerably lower than West Virginia stumpage values because of the lower timber quality, lack of available markets, and the amount of salvaged timber which was being cut.

Five hypothetical cases were then constructed to see how stand composition would affect the break-even point. Three species groups were used for the hypothetical stand analysis. These were red oak, chestnut oak, and other, the later includes yellow-poplar, red maple, sugar maple, black cherry, black gum etc. Only three species groups were used in the hypothetical stands to limit the number of different stand compositions and because these species would affect the benefits the most. Red oak and chestnut oak had high mortality rates so benefits would be high and the "other" species group suffered only minor losses and would derive lower benefits from spraying. The average volume per acre of 11.6 MBF/acre from the 106 research plots was used and the three species groups were broken up to represent different proportions to the total volume. Actual mortality ratios to predict the volume losses for each species were also taken from the values calculated for the 106 research plots.

The species composition for each of the hypothetical stands

| | Percent of Volume | | | | |
|---|---|---|---|---|---|
| **Species** | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 |
| Red Oak | 70 | 33 | 0 | 0 | 0 |
| Chestnut Oak | 30 | 33 | 70 | 30 | 0 |
| Other | 0 | 33 | 30 | 70 | 100 |

Benefit-cost analyses were conducted for each of the hypothetical cases to find the break-even spray cost. Each of the cases was analyzed using West Virginia and Maryland stumpage values and five and ten year spray intervals. The future costs were discounted to present values using a 6% interest rate. Stand age was assumed to be 60 years and rotation age was assumed to be 80 years.

## RESULTS

Because losses were so great on the 106 research plots, a landowner could afford to spray in any of the senarios using actual losses from our stands (Tables 2,3). Actual spray costs ranged from $2 per acre using fixed wing aircraft to spray tracts that are approximately 500 acres or larger in size to $50 per acre using helicopters and spraying less than 100 acres. However stumpage price does have a dramatic effect on the break-even cost as can be seen by comparing the present value (PV) of costs column in Tables 2 & 3.

The total value loss per acre, and break-even spray costs for the hypothetical

cases are shown in Table 4. The highest loss values and break-even spray costs occur in hypothetical cases 1, 2, and 3. In these cases the stand volume is made up mostly of one or both of the oak species. The oak species not only suffer high rates of mortality, but also have the highest stumpage values which adds up to extremely high value losses.

The lowest loss values and subsequent break-even spray costs occur in hypothetical cases 4 and 5. In these two cases the "other" species group makes up 70 and 100 percent, respectively, of the total stand volume. This species group consists cf speceis which are less vulnerable to mortality and have generally lower stumpage values.

Table 2..Economic Analysis for Actual Losses Using West Virginia Stumpage Prices.

| Species | Loss/Acre (Bdft) | WV Stumpage $/MBF | Value Loss/Acre $/Acre |
|---|---|---|---|
| Red Oak | 603 | $ 148 | $ 89 |
| Misc Oak | 396 | 98 | 39 |
| White Oak | 164 | 94 | 15 |
| Chestnut Oak | 1783 | 98 | 175 |
| Hickory | 420 | 88 | 37 |
| Other | 34 | 96 | 3 |
| | | Present Benefits = | $ 358 |

Break Even Cost Analysis - 5 Year Spray Interval

| Activity | Cost/Acre | Year | PV of Costs |
|---|---|---|---|
| Spray | $ 132 | 0 | $ 132 |
| Spray | 132 | 5 | 98 |
| Spray | 132 | 10 | 73 |
| Spray | 132 | 15 | 55 |
| | | Present Value of Costs = | $ 358 |

Break Even Cost Analysis - 10 Year Spray Interval

| Activity | Cost/Acre | Year | PV of Costs |
|---|---|---|---|
| Spray | $ 230 | 0 | $ 230 |
| Spray | 230 | 10 | 128 |
| | | Present Value of Costs = | $ 358 |

Table 3.--Economic Analysis for Actual Losses Using Maryland Stumpage Prices.

| Species | Loss/Acre (Bdft) | MD Stumpage $/MBF | Value Loss/Acre $/Acre |
|---|---|---|---|
| Red Oak | 603 | $ 70 | $ 42 |
| Misc Oak | 396 | 50 | 20 |
| White Oak | 164 | 70 | 11 |
| Chestnut Oak | 1783 | 50 | 89 |
| Hickory | 420 | 50 | 21 |
| Other | 34 | 50 | 2 |
| | | Present Benefits = | $ 185 |

Break Even Cost Analysis - 5 Year Spray Interval

| Activity | Cost/Acre | Year | PV of Costs |
|---|---|---|---|
| Spray | $ 69 | 0 | $ 69 |
| Spray | 69 | 5 | 51 |
| Spray | 69 | 10 | 37 |
| Spray | 69 | 15 | 28 |
| | Present Value of Costs | = | $ 185 |

Break Even Cost Analysis - 10 Spray Interval

| Activity | Cost/Acre | Year | PV of Costs |
|---|---|---|---|
| Spray | $ 119 | 0 | $ 119 |
| Spray | 119 | 10 | 66 |
| | Present Value of Costs | = | $ 185 |

Table 4.--Economic Analysis for Hypothetical Cases 1 Through 5 Using West Virginia and Maryland Stumpage Prices.

| Hypothetical Case | Total $ Loss/Acre | Spray Costs ($/Acre) Per 5 Year Interval | 10 Year Interval |
|---|---|---|---|
| Case 1 - WV | 595.00 | 218.00 | 381.00 |
| Case 1 - MD | 289.00 | 106.00 | 185.00 |
| Case 2 - WV | 428.00 | 157.00 | 274.00 |
| Case 2 - MD | 211.00 | 78.00 | 136.00 |
| Case 3 - WV | 479.00 | 175.00 | 306.00 |
| Case 3 - MD | 244.00 | 90.00 | 157.00 |
| Case 4 - WV | 237.00 | 88.00 | 152.00 |
| Case 4 - MD | 121.00 | 45.00 | 78.00 |
| Case 5 - WV | 56.00 | 20.00 | 36.00 |
| Case 5 - MD | 29.00 | 11.00 | 19.00 |

## CONCLUSIONS

The amount of mortality which will occur in any given forest stand depends on factors such as stand susceptibility and vulnerability; timing and intensity of defoliation, and number of defoliation events; climatic conditions before and after defoliation; secondary agents; and tree condition before and after defoliation.

The main objective of this study was to supply foresters and private landowners with an efficient method to determine whether or not spraying insec-

ticides to control imminent gypsy moth defoliation is feasible based on benefits and costs.

The highest benefit values and break-even spray costs were experienced on those stands which consisted mostly of vulnerable, high value species such as red and chestnut oak. Stands which consist mainly of less vulnerable and lower value species have lower benefit values and lower break-even spray costs.

From this study, landowners might conclude that they could afford to spray to protect their forest stands in almost any situation. This is probably not true. Normal mortality was not considered when calculating losses in this study. Landowners may also need to consider the fact that they may not get 100 percent protection from spraying insecticides. With decreasing effectiveness of spray, the benefit to cost relationship will become lower and the landowner can afford less to protect his or her forestland.

On the other hand, mortality losses could be underestimated because of factors such as aesthetic, wildlife, and recreation losses which cannot be measured in dollars and are not accounted for in this analysis. Other factors which will affect the break-even spray cost are salvage values, growth increase of residual trees, and the cost of survey and detection of insect populations.

Any landowner who is faced with defoliation by the gypsy moth should consider all of these factors along with their personal management objectives and the risks involved when conducting a benefit-cost analysis to determine the feasibility of spraying to control defoliation.

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# SITE FACTORS AND STAND CONDITIONS ASSOCIATED WITH OAK DECLINE IN SOUTHERN UPLAND HARDWOOD FORESTS[1/]

Dale A. Starkey and Steven W. Oak[2/]

**Abstract** -- Evaluations of oak stands from Virginia to north Georgia and west to Arkansas, Illinois and Missouri revealed that oak decline and mortality occurs over a wide geographic area, but that severity is highly variable. Site factors such as soil texture and depth, topographic position and site index were associated with high incidence and severity of oak decline and mortality. Plots with the highest incidence of mortality were characterized by shallow, rocky soils; were on ridge or upper slope topographic positions with west to north aspects; had average or lower site indices ($\leq 70$); and a predominance of red oak species (especially black and scarlet oaks). A general classification of mortality risk was assembled by combining these attributes with other factors such as recent history of defoliation and growing season precipitation. This classification may be used for identifying or prioritizing stands for regeneration, preventive or remedial silvicultural treatments and may suggest modification of management objectives. Since the association of site factors varies with geographical area, it may be possible to tailor risk rating systems to specific areas.

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## INTRODUCTION

Oaks comprise the most important group of upland hardwood trees in the eastern United States. They are widely distributed, abundant on a variety of sites, have relatively high timber values and contribute substantially to wildlife habitat quality and recreational opportunities. Oak decline is the most widespread, common, and perhaps complex disease problem of this group. Dieback and mortality occur in varying degrees causing loss in timber volume, growth, wildlife and recreational values (Starkey and Brown 1986).

Episodes of oak decline in the eastern U.S. have been reported since the early 1900's (Balch 1927) up to the present time. Cases have been reported from Arkansas (Rhodes and Tainter 1980, Lewis 1981, Mistretta _et al_. 1981, Bassett _et al_. 1982, Yeiser and Burnett 1982), Connecticut

(Dunbar and Stephens 1975), Florida (Lewis 1981), Massachusetts (Feder et al. 1980), Minnesota (Chapman 1915, Walters and Munson 1980), Mississippi (Lewis 1981), New Jersey (Kegg 1971), New York (Long 1914), North Carolina (Beal 1926, Tainter et al. 1984), Pennsylvania (Fergus and Ibberson 1956, Staley 1965, Nichols 1968, Wargo 1977), Virginia (Beal 1926, Rauschenberger and Ciesla 1966, Skelly 1974), West Virginia (Gillespie 1956, Staley 1965) and Wisconsin (Haack and Benjamin 1982).

Oak decline is a complex disease resulting from the interaction of predisposing stress factors with disease or insect pests which are secondary in action (i.e. not normally highly aggressive or capable of individually causing severe damage or death). Predisposing stress agents for the initiation of decline can be defoliating insects (Tryon and True 1958, Nichols 1968, Kegg 1971, Dunbar and Stephens 1975), drought (Balch 1927, Bassett et al. 1982, Tryon and True 1958, Rhodes and Tainter 1980, Lewis 1981, Mistretta et al. 1981, Tainter et al. 1983, Tainter et al. 1984), or late spring frost (Beal 1926, Balch 1927, Staley 1965, Nichols 1968). Secondary disease and insect pests acting in conjunction with stress agents are Armillaria root disease [Armillaria mellea], other root disease fungi such as Clitocybe tabescens, Corticium galactinum (Toole 1960, Filer and McCracken 1969), Ganoderma lucidum (Lewis 1981) and Polyporus dryadeus (Fergus 1956), canker fungi such as Hypoxylon spp. (Bassett et al. 1982, Lewis 1981) and the 2-lined chestnut borer (Agrilus bilineatus; Balch 1927, Dunbar and Stephens 1976, Cots and Allen 1980, Lewis 1981).

Trees react to stress of defoliation or prolonged drought by converting starch (stored in the roots) to sugar to support continued metabolism. This conversion is recognized by Armillaria mellea (Wargo 1972). This fungus commonly lives as a saprophyte on stumps and roots of dead trees in oak stands and can successfully colonize living tree root systems under stress. Other non-aggressive root disease fungi may act similarly. The 2-lined chestnut borer preferentially attacks weakened trees (Cots and Allen 1980, Haack and Benjamin 1982). The adult oviposits in bark crevices; the larvae then bore into the inner bark and create meandering galleries that partially or completely girdle the tree.

Root disease and stem girdling impair the internal water and food relations in the tree resulting in a progressive dieback of branches from the upper and outer crown, downward and inward. Other accompanying symptoms of these injuries may include chlorotic, dwarfed or sparse foliage; development of epicormic sprouts on the main bole and larger branches; premature autumn coloration; marginal leaf scorch; foliage wilt; foliage death; and sudden total tree mortality. Reduced shoot and diameter growth occurs in severely affected trees. While some dead trees show little evidence of prior decline, most have declined for 2 to 5 years or more before succumbing. Because of differences in the dynamics of internal water and stored food budgets (Kramer and Kozlowski 1960), physiologically mature trees may not be able to resume normal growth with the return of good growing conditions but continue to decline, while other physiologically less mature trees recover and rebuild their crowns. Patterns of decline and mortality may be easy or difficult to discern in forest stands, depending on the inciting stress factors, site conditions and species affected.

In the early 1980's, we received many reports which indicated that the southern U.S. sustained a substantial increase in oak mortality and decline. Inquiries of federal land managers and state foresters were made in late 1984 concerning the current status of oak decline in their areas of jurisdiction. Oak decline was reported across the south from Virginia to Arkansas, with concentrations in the Appalachian and Ozark Mountains (Starkey 1985). Damaged stands reported to us provided a population for evaluation. The main objective of this evaluation was to characterize oak decline sites with regard to species and size classes affected, the severity of decline and mortality, and site and stand factors associated with damage. A preliminary report of this evaluation has been published (Starkey and Brown 1986).

## MATERIALS AND METHODS

Thirty-eight sites were chosen for evaluation from the population of damaged stands (Starkey 1985). Criteria for selection included the absence of recent site disturbances (e.g., fire, logging, road construction), species composition predominantly oak, and an area uniform enough to be considered a stand-sized management unit (15-100+ acres). We attempted to achieve a dispersion of stands across the region where decline was reported (figure 1). Surveyed stand location by state and number were: Virginia (11), North Carolina (4), South Carolina (3), Georgia (2), Tennessee (5), Alabama (2), Illinois (2), Missouri (2), and Arkansas (7).

Each stand was sampled with 12 BAF 10 prism plots. Trees 5.5" and larger were tallied and classified according to crown position, and crown decline condition class (slight, <1/3 dieback; moderate, 1/3 - 2/3; severe, >2/3). Stand data recorded were elevation, slope, aspect, topographic position, soil depth and texture to 24 inches, and site index. The percentage of dominant and codominant trees in the various crown decline condition classes was compared for individual species and species groups and various site factors using analysis of variance, Duncan's Multiple Range Test, and occasionally chi-square analysis. The sampling

method used (probability of tree selection proportional to size) results in differences between the number of trees observed and the actual stocking (i.e. trees per acre) they represent. Therefore, data were transformed to reflect stocking rather than basal area. Crown decline condition classes were combined for some analyses. Suppressed and intermediate crown classes were omitted from analyses, because dieback and mortality caused by decline cannot be separated from that caused by overstory competition in these crown classes.

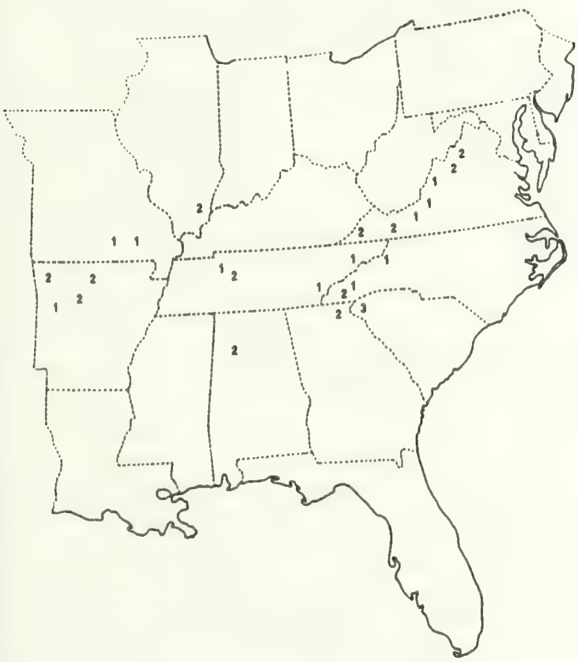

Figure 1.--Location and number of stands evaluated for oak decline severity, site and stand conditions.

## RESULTS

A total of 3,623 trees were observed in the 456 plots in 38 stands affected by oak decline. Of these, 2,810 were dominant or codominant and consisted of 84% oak (Quercus spp.), 6% hickory (Carya spp.), and 10% other species. The predominant species in the other category were maple (mostly red maple, Acer rubrum), yellow-poplar (Liriodendron tulipifera), black locust (Robinia psuedoacacia), and blackgum (Nyssa sylvatica). Evidence of 2-lined chestnut borer, other borers, Armillaria root rot and Hypoxylon canker were often seen. No symptoms typical of oak wilt (caused by Ceratocystis fagacearum) were observed.

### Severity of Decline

Eighty percent of all trees in oak decline areas showed some degree of decline or mortality (table 1). Twenty percent of these had advanced decline (> 1/3 crown dieback; moderate and severe classes combined) and 17% of the stocking was killed. We combined moderate and severely declined trees into an advanced decline condition class for analyses because of the relative infrequency of severely declined trees and because tree growth and vigor are most likely reduced when decline reaches these levels. Healthy and slight crown decline condition classes were likewise combined for some analyses.

### Site Factors

Associations were explored between damage severity and topographic position, slope class, aspect, soil texture, soil depth, and site index.

#### Topographic Position

Decline and mortality were present on all topographic position categories (ridge, slope, bench, terrace, and bottom), but there were adequate numbers of observations on only slope and ridge positions. Statistically significant differences occurred for mortality with ridges exceeding slopes (table 2). The inverse relationship was present for advanced decline but was not significant.

Table 2.--Percent of dominant and codominant trees in various crown condition classes for various site factors associated with affected stands

| Site Factors | Advanced | Dead |
|---|---|---|
| Topographic Position | | |
| Ridge | 17a[1] | 20a* |
| Slope | 20a | 16b |
| Slope Class | | |
| 0-20% | 15a | 20a* |
| 21-40% | 24a | 12b |
| >41% | 19a | 5c |
| Soil Texture | | |
| Stony/Gravelly | 9a** | 26a** |
| Other | 25b | 12b |
| Soil Depth | | |
| <18" | 14a* | 25a* |
| >18" | 27b | 8b |
| Site Index | | |
| <65 | 13a* | 22a* |
| 65-75 | 21ab | 16ab |
| >75 | 27b | 10b |

1/ Values in each group within a column are significantly different at the p = .05 (*) or p = .01 (**) level when followed by a different letter (analysis of variance or Duncan's Multiple Range Tests).

Table 1.--Percent of stocking of dominant and codominant trees by species and crown condition[1/]

| Crown Condition | Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | BLO | SCO | NRO | WHO | CHO | H | Other | All Species |
| Healthy | 9.5 | 8.0 | 8.5 | 31.4 | 13.5 | 23.4 | 63.5 | 20.4 |
| Slight | 40.5 | 39.4 | 52.5 | 38.6 | 60.6 | 47.6 | 22.9 | 42.8 |
| Advanced(*) | 16.5a[2/] | 29.7b | 28.6b | 18.5a | 21.3ab | 17.0a | 10.0 | 20.2 |
| Dead(**) | 33.5a | 22.9a | 10.4b | 11.5b | 4.6b | 12.0b | 3.6 | 16.6 |
| TOTAL | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

[1/] Species with > 100 observations (> 5% of the stocking).

[2/] Significance applies within but not among crown condition classes. Values followed by different letters are significant at the .01 level (**) or .05 level (*), as indicated for the crown condition class. Where no letters appear, F statistics were not significant and no Duncan's was performed.


Figure 2.--Average percent of dominant and codominant trees in the advanced and dead crown classes on various aspects.

### Slope Class

The effects of slope class were examined only for plots with a slope topographic position (65% of all plots). No significant differences in the percentage of healthy plus slight or advanced decline were found for slope class. Mortality, however, decreased significantly with increasing slope class (table 2).

### Aspect

Associations of damage with aspect were also examined only for plots with a slope topographic position. While no statistically significant differences existed, overall damage (advanced decline plus dead) was greatest in west to north aspects, least on northeast and east aspects, and intermediate in southeast to southwest aspects (figure 2).

### Soil Texture

Two broad soil texture categories were established because of the small number of observations in many individual classes. Stony or gravelly soils had significantly greater mortality than other soil textures (table 2; 26 vs. 12%; p = .01). The converse was true for advanced decline (9% for stony or gravelly soils, 25% for other textures). The healthy plus slight crown condition classes were approximately equal.

### Soil Depth

Soil depth classes were also combined into two classes, shallow (< 18" deep) and deeper soils (>18" deep). Results were similar to those for soil texture. Shallow soils had higher mortality levels than deeper soils (25 vs. 8%) while converse was true for advanced decline (27 vs. 14%; table 2). Both of these relationships were highly significant (p = .01).

### Site Index

All the factors previously discussed contribute to site index, the most commonly used measure of site productivity. Most individual factors associated with low site indices (i.e., shallow, stony soils on ridges) had the highest levels of correlation with mortality. This was also the case when site index of plots was analyzed (table 2). Mortality was 22% of stocking on low site indices (< 65 ft. at age 50) and only 15% on the highest site indices (> 75 ft. at age 50). Advanced decline, however, was higher on productive sites (28%) than on the least productive (18%). Both of these relationships were significant.

## Stand Factors

### Species Composition

Scarlet oak (Q. coccinea) accounted for over 20% of all trees on decline sites, followed by black oak (Q. velutina; 17%), white oak (Q. alba; 15%), and chestnut oak (Q. prinus; 12%). Hickories accounted for 7% of the stocking and the remainder was other species.

Species in the red oak group (ARO) were much more frequently damaged than those in the white oak group (AWO; table 3). The percentage of healthy red oaks was one-third that of white oaks, while the percentage of dead red oaks was three times that of white oaks. These differences were highly significant (p = .01). Advanced decline differed between the oak groups (similar to mortality) but the difference was not significant.

Table 3.--Percent of dominant and codominant red and white oak trees in various crown condition classes

| Crown Condition | Red Oaks | White Oaks |
|---|---|---|
| Healthy | 7a[1/] | 24b |
| Slight | 44a | 48a |
| Advanced | 24a | 19a |
| Dead | 24a | 9b |

1/ Significance applies within crown condition class. Values followed by different letters are significantly different at the p = .05 level according to analysis of variance.

Among oaks, black (BLO) and scarlet (SCO) oaks sustained the highest mortality levels (34 and 23%, respectively), followed by white oak (WHO), northern red oak (NRO), and chestnut oak (CHO; table 1). Among non-oak species, hickories (H) were most severely affected (12% mortality). Advanced decline was worst in scarlet, northern red (Quercus rubra), and chestnut oaks.

### Age

Evaluated stands were mainly sawtimber-sized with ages ranging from 50 to 110 years. Most were in the 60- to 80-year-old age class (31 of 38 stands). A few poletimber-sized stands of advanced age were encountered. Since our sampling did not include a wide range of ages, no firm conclusion can be drawn regarding age and decline. However, we limited our sampling to known areas of decline and can infer that damage is probably more common and severe in these older age and larger size classes. We received no reports of young poletimber-sized stands being affected.

### Basal Area

Basal area per acre (all crown classes) of evaluated stands averaged 87 square feet and varied little among stands (range from about 70 to 110 square feet). Several statistical analyses were performed on plot basal areas versus advanced decline and mortality but no significant relationships were detected. A representative portion of these data is presented in table 4.

Table 4.--Average percent of trees in various crown condition classes and basal area categories

| Basal Area (Sq. Ft. per Acre) | Advanced | Dead |
|---|---|---|
| <70 | 17[1/] | 17 |
| 70-80 | 17 | 17 |
| 90-100 | 13 | 21 |
| 110-120 | 12 | 18 |
| >120 | 18 | 19 |

1/ Values in columns are not significantly different.

## Risk Classification

The association of site and stand factors with decline severity can be used to construct a rudimentary classifcation for mortality (figure 3). We made no attempt to weight each of the individual site and stand factors according to the strength of the association with mortality. However, of the factors studied, aspect was not statistically correlated and should be

considered the weakest component of the rating system. Other analyses of these data (not presented here) indicate that some factors are more important in one geographic area and less important in another. Thus, risk rating systems may eventually be tailored to limited geographic areas where conditions may be more uniform.

| LOW DAMAGE POTENTIAL (MORTALITY RISK LOW) | | HIGH DAMAGE POTENTIAL (MORTALITY RISK HIGH) |
|---|---|---|
| ADEQUATE GROWING SEASON MOISTURE | <----> | ACUTE SUMMER DROUGHT (2-3 YRS. PRIOR) |
| NO RECENT OR REPEATED SPRING DEFOLIATION | <----> | RECENT OR REPEATED SPRING DEFOLIATION |
| PHYSIOLOGICALLY IMMATURE (POLE-SIZED, <60 YRS OLD) | <----> | PHYSIOLOGICALLY MATURE (SAWTIMBER, >60 YRS OLD) |
| COMPOSITON PREDOMINANTLY WHITE OAK GROUP | <----> | COMPOSITION PREDOMINANTLY RED OAK GROUP |
| HIGH SITE INDEX (>70) | <----> | LOW SITE INDEX (<70) |
| MESIC SITE CONDITIONS<br>Loamy soils, few rocks<br>Deeper (>18in) soils<br>Coves, terraces, bottoms, lower slopes<br>Northeast and east aspects | <----> | XERIC SITE CONDITIONS<br>Rocky soils<br>Shallow (<18in) soils<br>Ridges or upper slopes<br>South and West aspects |

Figure 3.--Classification system for oak mortality in the southern upland hardwood region.

## DISCUSSION

These results suggest that while decline may occur on all types of sites, it more commonly results in high mortality levels on sites of lower productivity. These are associated with ridges, gentler slopes, shallow, rocky soil and a predominance of red oak species. More productive sites may, however, exhibit high mortality if stand conditions are conducive to it (e.g., older stands with a predominance of black and/or scarlet oaks) and if stresses are severe or persist for long periods.

The simple mortality classification system presented here should be of use to managers in identifying stands and sites prone to decline and in prioritizing these for regeneration, preventive or remedial treatments. However, more information is needed to help make management decisions. For instance, data are needed to modify the risk rating to more accurately account for defoliation episodes by insects such as the gypsy moth. Since they tend to feed selectively on certain tree species, decline and mortality may develop differently than these results now indicate (Herrick and Gansner 1987). Also, risk rating needs to be tailored to more limited geographical areas such as the Ozarks, or the southern and northern Appalachians. A broader range of damage levels need to be examined to determine if decline as well as mortality can be included in a more sophisticated risk rating system. Such data are available from a recent survey of three upland hardwood areas in the South and will be incorporated in future analyses.

The implications of these data for the management of hardwood forests are several. Beyond the obvious loss of volume due to mortality and to reduced growth rates of severely declined trees, large losses of dominant oaks may greatly reduce mast yields for wildlife and reduce recreational values. On the other hand, small losses may be beneficial to wildlife in that extra den or cavity trees may be provided and small openings in an otherwise dense canopy created. Severe decline and mortality also makes the decision to carry or regenerate such stands a difficult one. If regeneration is delayed too long, affected stands may not develop the advanced reproduction necessary for regeneration, diseased root systems may not sprout with normal vigor or frequency and undesireable understory species may outcompete oak reproduction for newly available growing space. The species composition of declining stands is likely to shift away from the faster growing red oaks to the less-affected, slower growing white oaks. This may not be a problem if higher white oak compositions are desireable and adequate stocking of white oaks is present. Where white oaks are less abundant, other less desireable species will probably increase contributing to a reduction in timber and wildlife value.

Though oak decline has been a recurring condition with a long history in the east, it is not known if the current situation represents a permanent increase in damage occurrence or severity. More likely it is the result of short-term climatic stress and will dissipate before recurring again in the future. Past cutting practices, fire, woods grazing and the chestnut blight epidemic have had enormous impacts on the condition and species composition of southern oak forests. The resulting forests and species and trees we manage today may be less well adapted to the prevailing conditions than previous forests, especially under management regimes often being applied (i.e. long, sawtimber rotations). We have initiated other surveys which will provide data relative to the frequency and severity of oak decline over several upland hardwood areas in the South and provide a wider spectrum of data on the relationship of site and stand conditions to decline and mortality.

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# A FIVE YEAR RECORD OF CHANGE FOR A DECLINING SCARLET OAK STAND IN THE MISSOURI OZARKS 1/

Leo J. Johnson and Jay R. Law 2/

Abstract -- Oak decline following extreme droughts in 1980 and 1983 was monitored in an uncut 29-acre sixty-four year old scarlet/black oak sawtimber stand showing signs of decline, on the Winona District of the Mark Twain National Forest in Missouri. Annual evaluation of 74 overstory trees and reproduction on 30 1/735 acre plots in the stand shows that the percentage of dead trees in the overstory has increased from 36% in 1984 to 62% in 1987 and that tree species composition in the understory is shifting towards post oak (Quercus stellata Wangenh.) and white oak (Quercus alba L.) with red maple (Acer rubrum L.) and shortleaf pine (Pinus echinata Mill.) appearing even though good seed sources are not readily apparent. No significant increases in grasses, forbs, or undesirable woody vegetation has occurred.

Keywords: forest decline, Mark Twain National Forest, forest ecology, Quercus coccinea Muenchh., Quercus velutina Lam., Quercus stellata Wangenh., Quercus alba L., Acer rubrum L., Pinus echinata Mill.

## INTRODUCTION

As early as 1978, large numbers of trees in some scarlet oak stands on the Mark Twain National Forest began dying (Law and Gott 1987). A severe drought in 1980 (Decker 1986) significantly increased the number of oak sawtimber stands exhibiting signs of decline (Robbins et al. 1980). The area of the Forest reporting the largest number of declining stands was a three Ranger District unit with 321,000 acres of National Forest land located in Carter, Oregon, Ripley, and Shannon counties in south central Missouri.

A field survey of oak sawtimber stands there in 1982, found that stands where scarlet oak predominated or occurred in mixtures with black oak over the age of 60 years, located on broad flat ridges had the highest percentage of dead and declining trees (Auerbach 1982). With 70,000 acres of forest type 57 Scarlet Oak and an estimated volume of 28 million board feet in scarlet oak over the age of 60 (USDA-FS 1979), the loss of resource in the three Ranger District area, should the decline continue, could be significant to management (Law and Gott 1987).

Annual precipitation returned to near normal during 1981 and 1982 in the area of the decline. However, a drought of less duration (<4 months) occurred in 1983 from June through September, with two months classified as extreme (Decker 1986). Based on aerial reconnaissance in September and the interpretation of color-infrared photography flown in August of 1983 that showed increasing areas of stressed oak, a decision was made to continue a timber salvage sale program started in 1981.

A question remained: If no harvesting were done in the declining stands, how many trees with decline symptoms might recover? Our purpose was to study the change in health of individual trees in the overstory of a declining stand and the development of trees in the understory.

## MATERIALS AND METHODS

### Selection of Study Site

In the spring of 1984, a 29-acre segment of an 84-acre, 64-year old stand of scarlet oak sawtimber was left uncut. The larger area had

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been under consideration for a Research Natural Area designation under a cooperative study between the Forest Service's North Central Forest Experiment Station and the National Forest's Eastern Region. The area was seen as representative of the Society of American Foresters former Forest Type 41 Scarlet Oak (1967). This type was dropped in the 1980 Forest Cover Types of the United States and Canada by the Society. The Scarlet oak type is currently referenced as a variant of Type 44 Chestnut Oak (SAF 1980).

This study area was selected because 60% of the overstory trees were scarlet oak over the age of 60 years and the site had not been recently disturbed by fire or logging. The stand was typical of other declining stands as it already had 36% of the overstory in dead trees.

The rapidly deteriorating health of this sawtimber stand and others nearby, resulted in most of the oaks in the area being cut in salvage operations by 1984 with the exception of the reserved undisturbed 29-acre study stand. The study area was bordered on three sides by regenerating stands of oak and oak-pine seedlings/saplings and on the North side by a forest access road which separated the study stand from a young pole/sawtimber stand of mixed oak and shortleaf pine.

## PLOT ESTABLISHMENT

Eight 10 factor variable radius plots, two chains apart, were located in the center of the stand on the flatter section of the ridge so that influences from logging adjacent areas and topographic variations could be minimized. The center of each plot was marked and azimuths and distances to trees on the plot were recorded. No attempt was made to replicate the study or the plots as the major reason for the study was to observe and record change in the condition of the individual trees.

All trees 1.5 inches DBH and larger were recorded starting in the summer of 1984. Trees were tallied by species with DBH being measured to the nearest 1/10 of an inch. Based on the condition of the foliage and branches in the crown, each tree was assigned a decline status. A tree was listed as showing "symptoms of decline" if there was flagging (brown or red foliage), leaves were unusually small and yellowing, foliage was sparse, or the tree had one or more bare limbs above green branches.

The classification of "healthy" was given to trees with no symptoms of decline, those showing signs of recovery by refoliation and improved color in leaves, and with no dead branches in the upper crown above the first green branch. Those classified as dead were trees that had passed from a state of decline to one where no live foliage was present in mid or late growing season.

The plots were visited in the spring and fall to record the appearance of each tree at the start and end of the growing season to see what changes in tree health were taking place. All measurements and tree health classifications were done by the senior author. Earlier observations showed that some foliage would die shortly after reaching full leaf or in the last months of the growing season (late August or early September). Visits in the spring and fall were made to determine the best time of the year to evaluate the full impacts of decline.

Changes in the number of seedlings and saplings less than 1.5 inches DBH were recorded using four circular 1/735 acre plots located twelve feet in cardinal directions from the centers of the 10 factor B.A. plots. A total of 30 small plots were located. Considerable care was taken not to step inside the plot radius when recording information. These plots were also measured in spring and fall.

## RESULTS

### Species Composition

The overstory at first measurement in 1984 had 172 trees that were larger than 1.5 inches DBH. The major species was scarlet oak with 74 trees representing 43% of the trees in the stand. The next species with the highest number of trees was sassafras Sassafras albidum (Nutt.) Nees. with 50 trees accounting for 29%. Blackgum Nyssa sylvatica Marsh. was represented by 26 trees or 15% of the total number in the stand. Both sassafras and blackgum trees were intermediate or suppressed. Black oak Quercus veluntina Lam. and white oak Quercus alba L. each represented 5% of the overstory. Other dominants included four post oaks Quercus stella Wangenh. and one hickory Carya glabra (Mill.) Sweet.

The total stand stocking averaged 90 square feet of basal area per acre. The overstory was predominately scarlet and black oak sawtimber sized trees. The calculated number of trees per acre over 1.5 inch DBH was 172, based on the 74 trees recorded on the 8 plots.

There were 1594 trees per acre less than 1.5 inches DBH in the initial measurement of the 30 1/730 acre plots (see table 1). All of the species present in the overstory were represented in the initial inventory of seedlings. Red maple Acer rubrum L., which had not been recorded in the overstory plots, had 49 seedlings per acre. The stems of small blackgum and sassafras were believed to be too numerous to count. (See table 1.)

Table 1.--Number of Trees Per Acre found in four Measure-Measurements. From 30 1/735 acre plots. Trees 1.5" DBH and smaller.

| Species | Overstory Trees | Seedlings 1984 | Seedlings 1985/86 | Seedlings 1987 | Seedlings 1988 | Total Seedlings |
|---|---|---|---|---|---|---|
| Scarlet Oak | 74 | 171 | +74 | +147<br>-25 | +128<br>-25 | 470 |
| Black Oak | 9 | 74 | - | - | -25 | 49 |
| White Oak | 8 | 368 | +74 | +294<br>-74 | -49 | 613 |
| Post Oak | 4 | 809 | +49 | - | +49<br>-128 | 779 |
| Hickory | 1 | 123 | - | - | - | 123 |
| Blackgum | 26 | Numerous but not counted | | - | - | - |
| Red Maple | - | 49 | - | - | +49 | 98 |
| Pine | - | - | +25 | - | - | 25 |
| Sassafras | 50 | Numerous but not counted | | - | - | - |
| Total | 172 | 1594 | +222 | +342 | - 1 | 2157 |

Almost all of the seedlings, as counted in 1988, are still less than two (2) feet tall, with only a few of the blackgum, hickory, and sassafras being taller than two feet.

In 1984, most of the reproduction was post oak, white oak, and blackgum with minor amounts of desirable species. In 1985-86, there were substantial increases in reproduction of white, scarlet, and post oaks and pine. In 1987, there was another significant increase in white and scarlet oak seedlings, although each of them also had some one- or two-year old seedlings that died. The new seedlings appeared to be clumped around certain seed trees rather than uniformly distributed in the stand.

In the spring of 1988, several new seedlings were found, but a number of seedlings that were 1-2 years old the previous fall had disappeared. Overall, there was a net loss of 1 seedling per acre in 1988.

Over the course of four years, there has been an increase in seedlings, particularly ones of desirable species. There has not been a significant increase in grass, forbs, or undesirable woody vegetation, except in isolated openings.

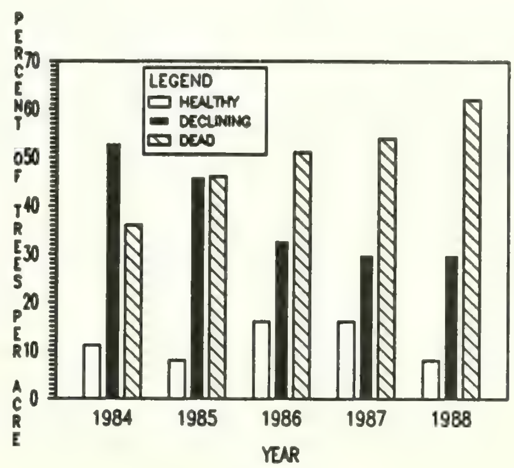


Figure 1.--Changes in health of trees in uncut stand of Scarlet Oak.

The observed changes in tree health over the five year period is shown in Figure 1. Since the summer of 1984, there has been a steady increase in the number of dead trees from 36% in 1984 to

62% in 1988. The number of trees classified as healthy has remained relatively unchanged, from 11% in 1984 to 8% in 1988. In 1986, it appeared that a recovery might be beginning, but by the fall of 1987, the trees that were apparently recovering were once again showing new signs of decline. In the spring of 1988, measurements showed that the conditions had worsened with only one tree showing signs of improved health, while eight others showed increasing signs of decline.

As of June 1988, only 24 of the 74 scarlet oaks were alive and all 9 of the black oaks were dead. The one hickory and all 50 of the sassafras present in 1984 had also died. Only 38% of the original overstory trees were alive at this spring remeasurement. All of the white and post oaks and blackgums were still considered healthy, showing no symptoms of decline. Only one of the surviving scarlet oak was considered to be in a healthy growing condition, while the other 23 had symptoms of decline.

## DISCUSSION

It had been recognized that the trees in the stand were predisposed to decline by a combination of adverse weather events (drought and snowless severe winters) and defoliations (late spring frosts and insect attacks such as the looper complex) and that it was the organisms of secondary action (OSA) such as Armillariella mella. Vahl., the black shoestring root rot and Agrilus bilineatus Weber, the two-lined chestnut borer that attacked the stressed trees and caused their death (Sinclair and Hudler 1988; Wargo 1977). We observed that these two agents were very active in the area of the declining stands (Law and Gott 1987; Robbins et al 1980).

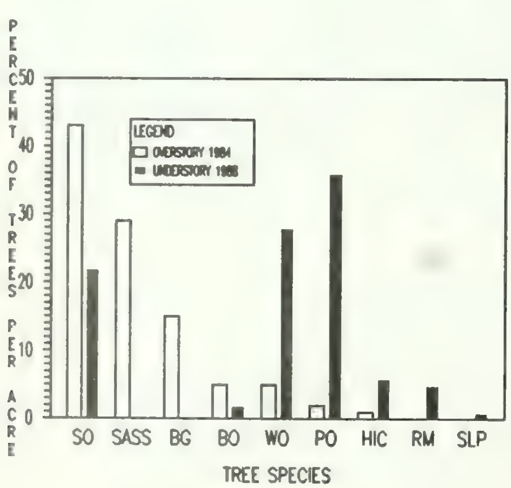


Figure 2.--Changes in species composition in declining Scarlet Oak stand.

By comparing the species composition of the overstory trees in 1984 with the seedling inventory of 1988 (Figure 2), it is apparent that the species change is from a scarlet/black oak type to a future stand with a greater mix of species and one with more trees of the white oak group. Seedlings of post oak, red maple and shortleaf pine are becoming established even though the seed source is sparse or almost non-existent in the immediate area.

At this time, almost all of the seedlings are less than two feet in height with only blackgum, hickory and sassafras having a few taller individuals. Based on an evaluation system for determining the adequacy of oak reproduction to replace the existing stand (Sanders et al 1984), a stocking value (SV) for the current regeneration was determined to be 5. To be able to reasonably insure that the oaks would survive and successfully compete with the many established blackgum and sassafras seedlings, should the overstory be completely removed, the size of the oak seedling would have to increase to where the stocking value was at least thirty, SV = 30. Due to the age and size of the overstory oaks and the fact that many of them are now dead or dying (and not resprouting), the contribution from stump sprouts to the regenerating stand, if the overstory trees were cut at this time, would be very small.

## SUMMARY

The observations made concerning the decline and subsequent mortality of scarlet and black oak sawtimber trees in a declining stand in this area of the Mark Twain National Forest are very limited. It is recognized that the reliability of any findings concerning changes in species composition could be improved through the replication of the study and the inclusion of a greater variety of forest conditions and locations.

The objective has been met of establishing a continuing record of changes in tree health for an uncut declining stand representative of common situations where all declining trees were being harvested. Recovery of older scarlet and black oaks now seems very doubtful where they are predominant in the composition of unlogged declining stands on the broad flat ridges of this three District area of the Forest.

This one situation does show that most trees that appear to be healthy and vigorous at the onset of a decline may remain in that condition for at least a five-year period if no other disturbance takes place. This study did not compare what happens to apparently healthy trees left after some harvesting had taken place in a declining stand with one where no man-caused

disturbances occur. A study of this nature would be helpful in making management decisions about future activities in declining stands.

The shift in species composition as shown in the development of tree seedlings in the understory is not totally surprising. The study area is located in Oak-Pine Breaks (Sandstone) landtype association based on the ecological classification system developed on the Mark Twain (Miller 1981). The stand is on an ecological landtype (ELT) 15 which is characterized by a flat landform on a neutral aspect with soils of sandstone origin such as captina and where the naturally occurring vegetation community is Dry chert forest.

In the Dry chert forest community on this ELT, the potential natural vegetation would have white oak, shortleaf pine, black and scarlet oak flowering dogwood, <u>Cornus florida L.</u> and Townbush blueberry <u>Vaccinium vacillans</u> Torr. as dominant plants (Miller 1981). The historic presence of shortleaf pine on the lands in this area has been well documented in the history of the lumber industry in the early days of settlement in Leslie Hills 1949 dissertation, <u>History of the Missouri Lumber and Mining Company 1880-1909.</u> This area has been mapped by Liming as being where the cover of the shortleaf pine was continuous in his <u>The Range of Shortleaf Pine in Missouri</u> (1946) and supported by in the U.S.D.A. - Forest Service publication <u>Atlas of United States Trees, Volume 1</u> (1971).

Fletcher and McDermott (1957) were able to correlate the occurrence of shortleaf pine with soils of sandstone origin (Roubidoux Formation), and the fact that it was the soil moisture regime that was the most important single factor to influence the relative abundance of pine over large areas. Steyermark (1940 and 1959) recognized oak-pine association as an edaphic climax type in the Ozarks.

The movement of the more drought-hearty shortleaf pine and white oak back to these upland Dry chert forests in south central Missouri may actually be a visual sign that the natural forces of the ecology of the Ozarks are again at work.

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REVITALIZING SLOW-GROWTH BLACK WALNUT PLANTINGS[1]

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Abstract.--Black walnut (Juglans nigra L.) can be successfully established on many sites; however, tree growth frequently declines to unacceptable rates because of interference by invading understory. In one slow-growing, 17-year-old walnut planting, eliminating the tall fescue (Festuca arundinacea Schreb.) understory by either semi-annual cultivation or annual reseeding with hairy vetch (Vicia vellosa Roth) reduced tree mortality and increased walnut diameter growth. Seeding with sericea lespedeza (Lespedeza cuneata (Dumont) G. Don.) was not as effective as cultivation. Black walnut lateral shoot growth, leaf length and number, leaf leaflet number and area, and leaflet retention also were increased when the tall fescue was removed. The results suggest that slow growth in walnut plantings with tall fescue understories results more from competition for soil nitrate nitrogen than for soil moisture.

## INTRODUCTION

Successfully establishing black walnut plantations (Juglans nigra L.) is common now that the importance of controlling weeds during the first 3 to 5 years is recognized. It is commonly believed that continued weed control is not necessary after walnut trees have overtopped the herbaceous competition; however, pure walnut plantings usually do not dominate a site sufficiently to exclude interfering understory vegetation. Because walnut flushes later in the spring and drops its leaves sooner in the fall than most other hardwoods, many cool-season forbs and grasses are not shaded out. At full site occupancy, about 45 percent of the solar radiation still reaches the understory in walnut plantings (Schlesinger and Van Sambeek 1986).

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Previous research has shown that the type of understory vegetation can affect walnut growth. Van Sambeek (1988) reported that sowing hairy vetch, an annual cool-season legume, between rows of walnut seedlings can accelerate early walnut growth. He also showed that underplanting perennials, such as crownvetch and sericea lespedeza, can stimulate growth of established walnut saplings. Roth and Mitchell (1982) tested the effects of eight ground covers on walnut growth and found the best growth with sericea lespedeza and the poorest growth with tall fescue. Todhunter and Beineke (1979) described an interaction for height growth among half-sib walnut progeny growing on an area with dense tall fescue cover and an area with 70 percent forbs. They attributed reduced walnut growth to severe competition for soil moisture and nutrients by tall fescue.

Black walnut is responsive to removing grass sods. Holt and Voeller (1975) demonstrated that after 4 years of complete weed control in a 10-year-old walnut orchard, diameter growth and nut production for treated trees were nearly double that of trees growing in fescue sod. Recently, von Althen (1985) reported that chemical weed control around 8-year-old walnut saplings increased annual height growth by more than 0.5 m over trees in quackgrass sod. Increased growth was accompanied by increases in leaf length and foliar nitrogen content. In one slow-growing walnut plantation, growth increased in proportion to the area of chemical weed control up to complete removal of a smooth bromegrass sod (Miller et al. 1987).

The objectives of our study were to determine to what extent an observed growth decline in walnut trees with a tall fescue understory could be reversed, what types of vegetation management practices are most effective, and what factors are involved in the interference process.

## MATERIALS AND METHODS

Our study began in 1981 in a walnut planting on a wide floodplain adjacent to Indian Creek in Jackson County, Illinois. The planting was established in the spring of 1965 with 1-0 seedlings at a spacing of 3.7 m by 6.1 m. Annual mowing between 1973 and 1981 resulted in the development of a dense, tall fescue (Festuca arundinacea Schreb.) sod. During this same period, walnut height growth slowed and some of the trees began to show top dieback and epicormic sprouting along the main bole. In addition, total mortality had increased from less than 2 percent in 1972 to 8 percent in 1981 when the ground cover study began.

The soils are a mixture of Sharon silt loam (a coarse-silty, mixed, acidic, mesic, Typic Udifluvent) and Bonnie silt loam (a fine-silty, mixed, acidic, mesic, Typic Fluvaquent). These soils are classified as suitable to questionable for growing walnut because of their poor internal drainage (Losche et al. 1980). Some mottling is present within the 1.5 m deep silty loam topsoil that overlies a fine gravelly or silty sand layer.

Twelve plots of 9 to 15 trees each were identified in the summer of 1981. Each plot was separated by a 3.7-m- or 6.1-m-wide tall fescue isolation strip. The plots were stratified (blocked) into small, average, and large dbh-size classes. The following four treatments were assigned randomly within each stratum: (1) retain tall fescue sod (check), (2) cultivate semi-annually (May and August), (3) cultivate and seed to a perennial legume, and (4) cultivate annually and reseed to an annual legume. Because the crownvetch (Coronilla varia L.) seeded in 1981 failed to become established, treatment 3 was reseeded with sericea lespedeza (Lespedeza cuneata (Dumont) G. Don.) in the spring of 1983. Treatment 4 has been cultivated annually in August and reseeded with hairy vetch (Vicia vellosa Roth). Because the planting was on a wide floodplain, we did not use a complete chemical control treatment with pre- and post-emergent herbicides. The plantation was thinned in 1981 before beginning treatments to avoid possible confounding with intraspecific competition.

Annual measurements since 1982 include dbh, total live tree height and lateral shoot elongation. Composite foliage samples were collected in late June from each plot by removing leaflets of one mid-shoot leaf from a mid-crown branch on the south side of each tree. Foliar samples were analyzed for total nitrogen by the Kjehldahl method, phosphorus by the vanadomolybdophosphoric yellow method, and potassium by flame emission. Composite soil samples were collected each fall from each plot from three randomly located positions at four depths (0-20, 20-40, 40-60, and 60-80 cm). They were analyzed for pH in a 1:2 soil:water solution, for nitrate nitrogen and phosphorus by colorimetry, for potassium by flame emission, and for organic matter content by loss-on-ignition.

The study was expanded in 1985 and 1986 to determine what factors were associated with differences in tree growth. In the spring of 1985, point dendrometers were placed on three trees randomly located within each plot and read semi-weekly during the 1985 and 1986 growing seasons. In late June, number of leaves per elongating shoot, leaf rachis length, and number and area of leaflets per leaf were also determined on the same material used for the foliar nutrient analyses. In May, July, and October, standing biomass from six 0.3- by 0.3-m subplots within each plot was harvested at the ground line and separated into legumes, other forbs, grasses, and detritus to determine oven dry weights. Percent crown defoliation for all trees was visually estimated to within 5 percent weekly from August through September. Two observers independently estimated the defoliation and then these figures were averaged.

In the spring of 1986, three soil moisture tensiometers were placed randomly within each plot to determine soil moisture deficits at a depth of 60 cm. Daily readings of soil moisture deficit below -10 centibars (field capacity) were summed for each plot to determine cumulative stress days from April 10 to October 7. Daily rainfall was determined with a recording rain gauge.

Analysis of variance was used to interpret results; differences were considered significant at the 5 percent level. Because strata were the replications in this study, the interactions between strata and ground cover treatments could not be determined. A split-plot design using year as a subplot was used to examine for interactions between year and ground cover treatments. Multiple comparisons were made with Duncan's New Multiple Range Test. Average radial growth increments through the growing season were fitted to a polynomial equation to determine Julian dates for 10 and 90 percent of growth completion for each plot (Bocoum 1987). A similar procedure was used to determine Julian dates for 50, 75, and 95 percent defoliation.

## RESULTS AND DISCUSSION

### Tree Growth Characteristics

Retaining the tall fescue sod resulted in continued tree decline as previously reported by Schlesinger and Van Sambeek (1986) and subsequent mortality as reported here (fig. 1). Conversely,

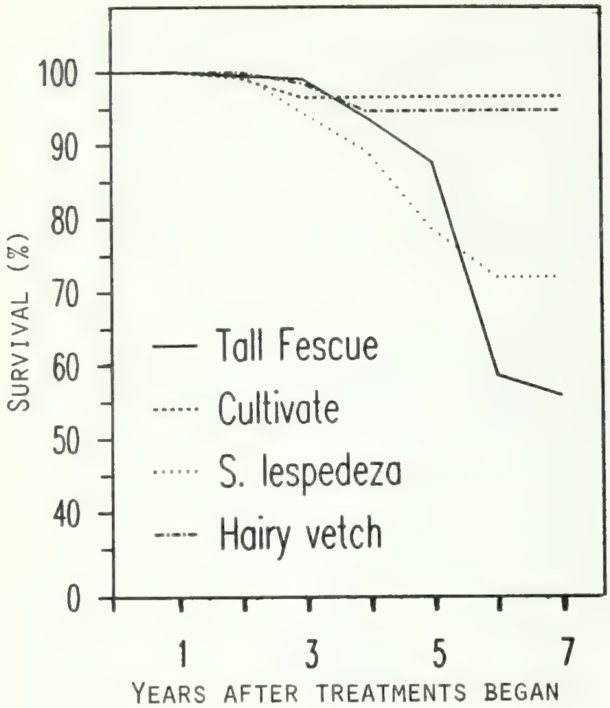


Figure 1.--Walnut survival in a 17-year-old, slow-growth planting by ground cover treatment.

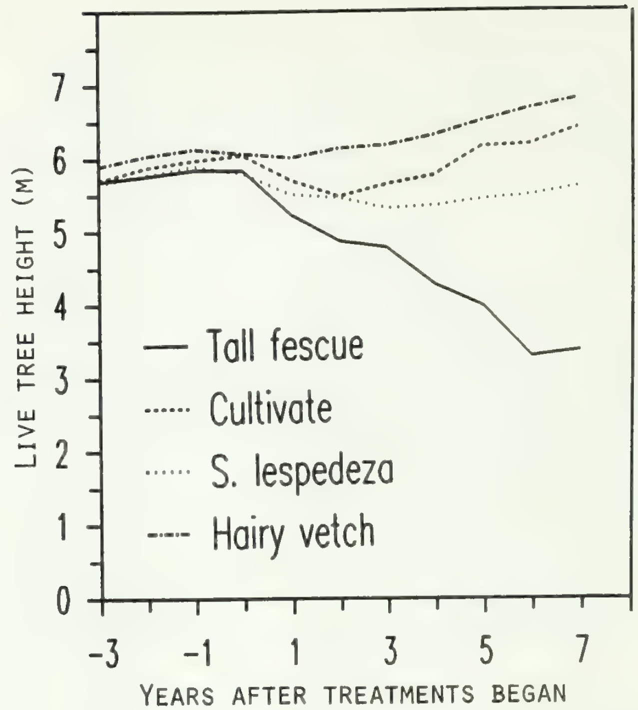


Figure 2.--Average height of study trees before and after ground cover treatments. Treatments began in the fall of 1981 (year 0).

most trees in the semi-annually cultivated and hairy vetch plots ceased crown dieback and developed normal crowns. Trees in the plots seeded with a perennial legume showed a mixed response where tall fescue remained the dominant vegetation until 1986 when sericea lespedeza became the dominant vegetation.

After beginning ground cover treatments, the check treatment showed net negative height growth because each year one or two trees had crown dieback that was not offset by the small increment of height growth on the other live trees (fig. 2). Before beginning ground cover treatments, height growth for all the walnut trees still alive in 1982 had averaged only 0.07 meters annually for the three preceding years. If all live trees during this period had been included, overall annual height growth would have been negative and similar to the growth observed in the check plots after ground cover treatments and begun.

Annual height growth improved first in the plots seeded to hairy vetch and next in those that were cultivated semi-annually (fig. 2). Net negative height growth continued for 3 years in the sericea lespedeza plots where a few trees continued to decline while the majority eventually began to recover. The initial recovery when underplanted with sericea lespedeza was probably in response to the fall 1981 cultivation when seeded to crownvetch and the spring 1983 cultivation when seeded to sericea lespedeza.

Walnut dbh growth showed a slightly different pattern from that of height growth because declining trees do not show marked reductions in stem diameter (fig. 3). Annual dbh growth for the check trees averaged only 0.07 cm, which was less than the 0.12 cm of annual dbh growth that occurred for the 5 years preceding the start of ground cover treatments. Annual dbh growth in the semi-annually cultivated, hairy vetch, and sericea lespedeza plots averaged 0.39, 0.35, and 0.17 cm, respectively. None of the treatments restored annual dbh growth to 0.66 cm, the level that occurred for the first 10 years following plantation establishment (Schlesinger and Van Sambeek 1986).

Differences in radial growth, determined with point dendrometers, were found for time of growth initiation and completion among the dbh strata but not among ground cover treatments (table 1). Trees in the semi-annually cultivated and hairy vetch plots grew approximately 10 days longer than trees with a fescue or sericea lespedeza understory. This difference was not statisticially different because the error term contains a large stratum x treatment interaction. For the semi-annually cultivated plots,

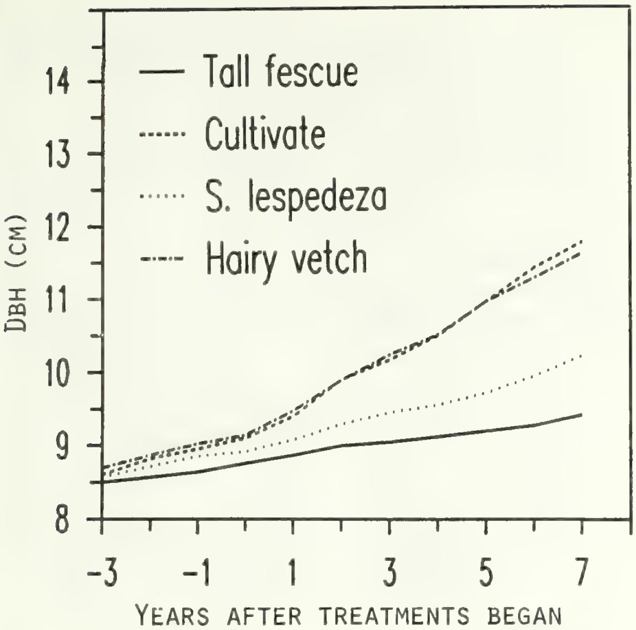


Figure 3.--Average stem diameter before and after ground cover treatments. Treatments began in the fall of 1981 (year 0).

annual growth of the trees in the small dbh stratum was more than twice (0.30 cm) that of the trees in the average dbh stratum (0.13 cm).

Lateral shoot or limb growth for walnut in the semi-annually cultivated and hairy vetch plots was nearly two times that of trees with a tall fescue understory (table 2). Holt and Voeller (1972) found similar increases during the first year after walnuts were chemically released from tall fescue understories.

Walnut leaf rachis length for trees in the semi-annually cultivated and the hairy vetch plots was 19 and 17 percent greater, respectively, than for trees in the fescue sod plot (table 2). Increased walnut leaf length also was reported by von Althen (1985) for trees chemically released from a quackgrass sod. In addition to increased leaf length, trees in the semi-annually cultivated and hairy vetch plots averaged 15.7 leaflets per leaf compared to 14.3 for trees with a tall fescue or sericea lespedeza understory. Increased leaf length was accompanied by a 42- to 57-percent increase in total leaflet area per leaf. The increase in leaflet area, along with a greater number of leaves, gave the trees in the treated plots a 31- to 68-percent increase in potential photosynthetic area on each limb over trees in the check plots. New growth on trees in the large dbh stratum also had more and longer leaves than trees in the small dbh stratum (table 2).

Semi-annual cultivation and annual reseeding with hairy vetch affected leaf color and retention. Leaflets in these treatments were greener in July and August than those for trees with a tall fescue or sericea lespedeza understory. In addition, the foliage for these same treatments remained on the trees 6 to 13 days longer than for trees with a tall fescue or sericea lespedeza understory (table 3). A similar pattern was observed among dbh strata. The large dbh trees retained their greener foliage for 13 to 15 days longer than the small dbh trees.

Table 1.--Mean dates for initiation and completion of walnut radial growth in 1985 and 1986 by ground cover treatments and dbh strata.

| Variable | Date for 10% of growth | Date for 90% of growth | Growth duration |
|---|---|---|---|
| | | | -days- |
| GROUND COVER: | | | |
| Cultivated | May 6 a[1] | July 15 a | 70 a |
| Hairy vetch | May 3 a | July 14 a | 72 a |
| S. lespedeza | May 5 a | July 5 a | 61 a |
| Tall fescue | May 5 a | July 6 a | 62 a |
| DBH STRATA: | | | |
| Large | May 8 a | July 19 a | 71 a |
| Average | May 4 b | July 12 a | 69 a |
| Small | May 2 b | June 28 b | 58 b |

[1] Dates and means followed by the same letter within groups are not different at the P > 0.05 level.

Table 2.--Effect of ground cover treatment and dbh strata on walnut lateral shoot and leaf growth.

| Variable | Lateral shoot length | Leaves per new shoot | Leaf rachis length | Leaflet area per leaf |
|---|---|---|---|---|
| | -cm- | -no.- | -cm- | $-cm^2-$ |
| GROUND COVER: | | | | |
| Cultivated | 11.7 a[1] | 11.2 a | 31.2 a | 210 ab |
| Hairy vetch | 11.0 a | 10.3 ab | 30.7 ab | 232 a |
| S. lespedeza | 8.0 b | 10.2 ab | 27.8 b | 183 bc |
| Tall fescue | 6.6 b | 9.6 b | 26.2 c | 148 c |
| DBH STRATA: | | | | |
| Large | 9.9 a | 11.3 a | 30.9 a | 226 a |
| Average | 9.2 a | 9.9 b | 29.1 ab | 200 a |
| Small | 8.8 a | 9.8 b | 26.9 b | 154 b |

[1] Means followed by the same letter within groups are not different at the P > 0.05 level.

Table 3.--Dates for 50, 75, and 95 percent walnut defoliation by ground cover treatment and dbh strata.

| Variable | Date for 50 % defoliation | Date for 75 % defoliation | Date for 95 % defoliation |
|---|---|---|---|
| GROUND COVER: | | | |
| Cultivated | Sept. 7 a[1] | Sept. 18 ab | Oct. 1 b |
| Hairy vetch | Sept. 9 a | Sept. 21 a | Oct. 5 a |
| S. lespedeza | Sept. 1 ab | Sept. 11 bc | Sept. 25 c |
| Tall fescue | Aug. 25 b | Sept. 8 c | Sept. 25 c |
| DBH STRATA: | | | |
| Large | Sept. 12 a | Sept. 24 a | Oct. 7 a |
| Average | Aug. 29 b | Sept. 11 b | Sept. 27 b |
| Small | Aug. 28 b | Sept. 9 b | Sept. 23 c |

[1] Dates followed by the same letter within groups are not different at the P > 0.05 level.

Table 4.--Average oven-dry biomass for grasses, legumes, other forbs, and detritus during the 1985 and 1986 growing season by ground cover treatment and season of harvest.

| Variable | Grasses | Legumes | Other forbs | Detritus |
|---|---|---|---|---|
| | g/m² | | | |
| GROUND COVER: | | | | |
| Cultivated | 77 b[1] | 26 b | 10 a | 45 c |
| Hairy vetch | 97 b | 34 b | 4 a | 124 b |
| S. lespedeza | 177 a | 122 a | 40 a | 231 a |
| Tall fescue | 224 a | 5 b | 18 a | 193 a |
| SEASON: | | | | |
| Spring | 164 a | 45 ab | 15 a | 189 a |
| Summer | 103 b | 34 b | 16 a | 146 b |
| Autumn | 165 a | 61 a | 22 a | 110 b |

[1] Means followed by the same letter within groups are not different at the P > 0.05 level.

## Site Factors Affecting Tree Growth

Understcry biomass in the semi-annually cultivated and hairy vetch plots was approximately half that in the tall fescue plots (table 4). Although grasses were the predominant live ground cover in all treatments, tall fescue made up only 40 and 51 percent of the grasses in the semi-annually cultivated and the hairy vetch plots, respectively. Within the check and the sericea lespedeza plots, tall fescue made up 82 and 78 percent of the grasses, respectively. Legume biomass increased rapidly between the 1985 and the 1986 growing seasons in the sericea lespedeza plots, averaging 35 $g/m^2$ during the second year after seeding and 208 $g/m^2$ during the third year after seeding. The principal legumes in the cultivated plots were annual hop clover and invading hairy vetch. Other forbs made up a minor component in this planting and showed no differences among treatments or dbh strata. The average amount of dead and decaying vegetation was highest in the sericea lespedeza and the tall fescue plots and lowest in the semi-annually cultivated plots.

Differences in cumulative soil moisture deficits among ground cover treatments were not well correlated with the amount of understory biomass. The cumulative soil moisture deficit for the 180-day growing season was greatest in the hairy vetch plot and least in the tall fescue plots (fig. 4). Soil moisture was below field capacity for 136, 150, 165, and 143 days in the tall fescue, sericea lespedeza, hairy vetch, and semi-annually cultivated plots, respectively. It rained frequently throughout the growing season except for one 22-day period during which we recorded soil moisture tensions of -70 centibars in a dense stand of sericea lespedeza. The high average soil moisture deficits in the hairy vetch

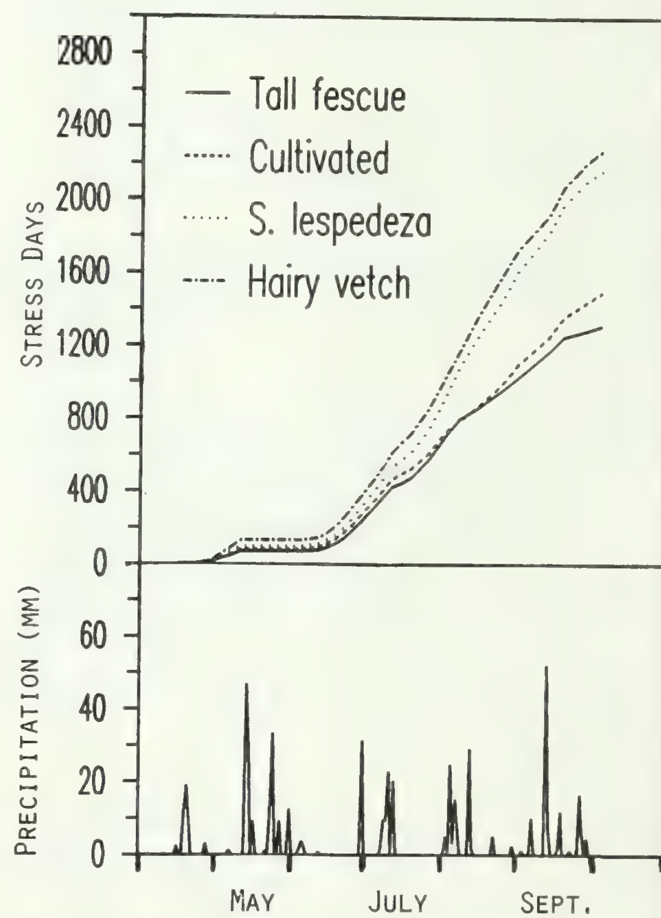


Figure 4.--Cumulative stress days (centibars per day) by ground cover treatments and daily precipitation from April 10 to October 7.

plots (table 5) possibly resulted from a dense stand of green and yellow foxtail that developed after the thin stand of hairy vetch matured and died in June. Available soil moisture under tall fescue, a cool-season grass, may have remained high because the fescue was not cut and allowed to seed and mature. The mature vegetation thereby acted as a mulch for most of the growing season.

Cumulative soil moisture deficits were greater in the large dbh stratum than in the small dbh stratum (table 5). Soils in the large dbh stratum are primarily Sharon silt loams, which have less silt and more sand than soils in the small dbh stratum, which are primarily Bonnie silt loams. Clay averaged 9 percent across the planting with no differences among strata. Thus, soil moisture deficits may have been highest in the large dbh stratum because of reduced water holding capacity and/or higher transpiration rates from the larger trees and understory vegetation. In addition, the coarse-silty nature of the Sharon silt loams probably resulted in better soil aeration leading to better walnut root growth.

Soil nitrate nitrogen was significantly higher in the semi-annually cultivated and hairy vetch plots than in the tall fescue plots, especially in the top 40 cm (fig. 5). Examination of the interaction between ground cover treatments and soil depth revealed that soil nitrate nitrogen in the upper soil depths (0 to 20 and 20 to 40 cm) for the semi-annually cultivated or hairy vetch plots averaged between 7 and 18 mg/kg nitrate nitrogen, while the plots with a tall fescue cover averaged less than 6 mg/kg at all four soil depths. Soil nitrate nitrogen increased in the sericea lespedeza plots after the two cultivations and four years after seeding sericea lespedeza.

Table 5.--Soil texture and average growing season soil moisture tension in 1986 by ground cover treatment and dbh strata.

| Variable | Texture Silt | Texture Sand | Organic matter | Soil moisture tension |
|---|---|---|---|---|
| | - - - - | percent | - - - - | - bars - |
| GROUND COVER: | | | | |
| Cultivated | 65.3 a[1] | 27.3 a | 3.00 a | -0.166 a |
| Hairy vetch | 62.0 a | 28.7 a | 2.90 a | -0.237 b |
| S. lespedeza | 66.0 a | 24.7 a | 3.03 a | -0.195 ab |
| Tall fescue | 61.3 a | 27.3 a | 2.92 a | -0.140 a |
| DBH STRATA: | | | | |
| Large | 58.5 a | 31.0 a | 2.95 a | -0.216 b |
| Average | 68.0 b | 24.7 a | 3.02 a | -0.173 ab |
| Small | 64.5 ab | 26.5 a | 2.91 a | -0.164 a |

[1] Means followed by the same letter within groups are not different at the P > 0.05 level.

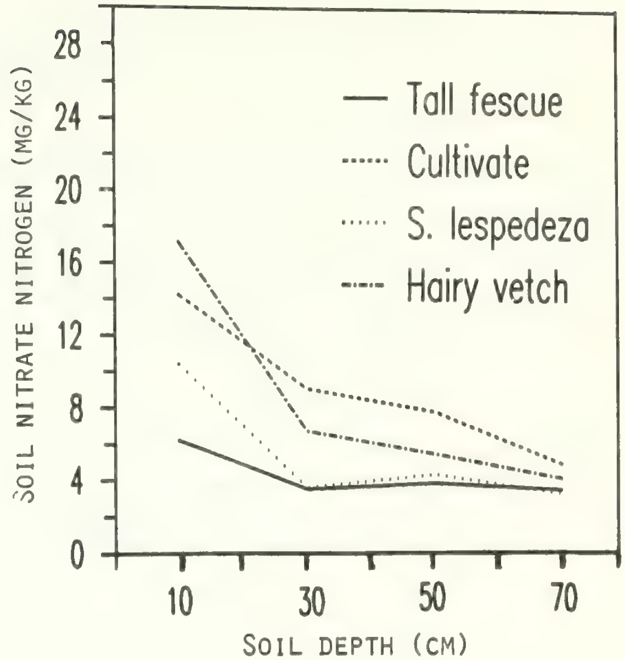


Figure 5.--Average soil nitrate nitrogen in the top 80 cm during the 6 years after the ground cover treatments were established.

The ground cover treatments have had no measurable effect on soil pH, available phosphorus, exchangeable potassium, or organic matter content. Soil pH, phosphorus, potassium, and organic matter averaged 6.0, 75 mg/kg, 84 mg/kg, and 2.96 percent across the planting, respectively. Except for potassium, which is low, these nutrients are at an acceptable level for growing black walnut. No differences among the strata were found for soil pH, phosphorus, potassium, or organic matter.

Increased soil nitrate nitrogen was associated with increased walnut foliar nitrogen (table 6). An interaction for foliar nitrogen content occurred among the ground cover treatments and the number of years after begining treatments. Initially, foliar nitrogen increased in all plots that were cultivated to establish the ground cover treatments but not in the check treatment where tall fescue was retained. Thereafter, walnut foliar nitrogen content was higher in the semi-annually cultivated and the hairy vetch plots than in the sericea lespedeza and tall fescue plots. Walnut foliar nitrogen again increased in sericea lespedeza plots following its establishment in 1986. Throughout the ground cover study, walnuts with a hairy vetch understory consistently had the highest foliar nitrogen content.

Although foliar nutrient levels were not determined before beginning the study, the

Table 6.--Average walnut foliar nutrient content for the 6 years after ground cover treatment.

| Variable | Leaflet dry wt. per leaf | Total N | P | K |
|---|---|---|---|---|
| | - g - | - - - - | percent | - - - - - |
| GROUND COVER: | | | | |
| Cultivated | 1.74 a[1] | 2.10 b | 0.23 a | 1.00 a |
| Hairy vetch | 1.68 a | 2.24 a | 0.24 a | 1.24 a |
| S. lespedeza | 1.58 a | 1.97 c | 0.24 a | 1.30 a |
| Tall fescue | 1.22 a | 1.91 c | 0.25 a | 1.26 a |
| DBH STRATA: | | | | |
| Large | 1.61 a | 2.12 a | 0.24 a | 1.24 a |
| Average | 1.53 a | 2.05 b | 0.24 a | 1.20 a |
| Small | 1.53 a | 2.00 b | 0.24 a | 1.16 a |

[1] Means followed by the same letter within groups are not different at the P > 0.05 level.

observed increases in leaf rachis length, number and area of leaflets per leaf, and leaf color following cultivation suggest that the trees were nitrogen deficient (Phares and Finn 1971). Fertilization studies with young walnut suggest that trees with foliar nitrogen levels below 2.0 percent will usually respond to adding nitrogen. Walnuts released from a tall fescue understory apparently have responded to nitrogen released from decaying tall fescue residues, increased mineralization of organic matter, and/or fixed nitrogen released by the introduced legumes.

Our results suggest that periodically adding a high nitrogen fertilizer to slow-growth plantings with a tall fescue understory might revitalize these plantings. Both Peters and Luu (1984) and Creek and Wade (1985) have shown that tall fescue produces phytotoxins that slow the growth of associated vegetation. Subsequently, Rink and Van Sambeek (1985) demonstrated that growth of black walnut seedlings could be reduced by applying tall fescue leachates. The above studies on tall fescue interference combined with the results reported in this manuscript strongly suggest that grass sods must be removed to revitalize slow-growth walnut plantings.

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# THE EFFECT OF ROOT PRUNING TREATMENTS ON RED OAK SEEDLING ROOT GROWTH CAPACITY[1]

Charles J. Barden and Todd W. Bowersox[2]

Abstract. -- The study evaluated the influence of pre-sowing radicle clipping and lateral root pruning in the nursery on shoot morphology, root morphology, and root growth capacity (RGC) of 1-0 northern red oak seedlings. The radicle clipping treatment produced multiple taproots. No root treatments adversely affected seedling shoot size when compared to the control treatment. There was a highly significant interaction ($p < .001$) between the radicle clipping and lateral pruning treatments, resulting in a doubling of RGC (number of new roots) in comparison to control seedlings. However, either treatment alone resulted in no significant increases in RGC. The results suggest that the treatments may be useful in improving northern red oak seedling field performance.

## INTRODUCTION

The difficulty of regenerating oak stands after cutting is not a new problem facing foresters (Carpenter and Guard 1954). Studies have documented the need for adequate advance oak regeneration to be present before harvest in order to ensure that oak is a major component of the next stand (Clark and Watt 1971, Johnson 1979, Ward 1966). Artificial regeneration via planting of nursery stock has been proposed as a solution to the lack of adequate advance regeneration. However, with a few notable exceptions (Foster and Farmer 1970, Wendel 1980), survival and particularly growth of planted oaks has been poor (Farmer 1981, Loftis 1979, McGee and Loftis 1986).

The slow growth and poor survival of planted oaks may in part be due to the root system attributes of the seedling. The taproot of a one year old northern red oak (Quercus rubra L.) seedling may penetrate forest soils to a depth of 45 cm (Lyford 1980), whereas nursery lifting usually severs all roots at a depth of about 20 cm. The drastic loss of root area from lifting may have a long-term negative influence on shoot growth.

Carpenter and Guard (1954) proposed pre-germinating acorns and interrupting the radicle at the time of sowing to induce a more branched root system. More recently, Bonner (1982) reported that spring sowing of pre-germinated cherrybark oak (Q. falcata var. pagodaefolia Ell.) and Shumard oak (Q. shumardii Buckl.) acorns with damaged radicles resulted in a multiple, branched taproot. These seedlings were slightly, but not significantly smaller than seedlings grown from undisturbed spring-sown acorns.

We hypothesized that a multiple taproot system might result in more root area in the upper soil levels, which would be retained by the seedling during lifting. Farmer (1975) observed that most new roots in transplanted oaks arise from near the cut surface of the taproot; thus a seedling with multiple taproots would have more potential sites for root regeneration.

Root growth capacity (RGC) is the ability of a seedling to rapidly grow new roots when placed in a controlled environment (Stone 1955). RGC is measured by pruning the root system to a specified length, removing all new white roots from a seedling, and planting the seedling in a controlled environment for a set period, usually

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3-5 weeks. At the conclusion of this period the root systems are excavated and the new root growth quantified.

RGC studies for a variety of tree species have been reviewed by Ritchie (1985), and Ritchie and Dunlap (1980). Root growth capacity has been correlated with early survival and growth in the field with several species, including northern red oak (Webb and von Althen 1980) and loblolly pine (Pinus taeda L.) (Barden et al. 1987, Feret and Kreh 1985). The objective of this study was to determine if radicle clipping and lateral root pruning can influence the shoot morphology, root morphology, and RGC of 1-0 northern red oak seedlings.

## METHODS AND MATERIALS

Acorns were collected from several planted northern red oak trees on the Penn State University campus in State College, Pennsylvania, during September and October of 1986. The acorns were held uncovered indoors for 2 weeks at room temperature, and overwintered in cold storage at 1°C in covered containers. They were removed from storage in May 1987, soaked in tap water for 24 hours at room temperature and allowed to sprout before planting. The emerging radicle on half of the acorns was clipped off by cutting with a razor blade. In June 1987 the acorns were planted into 3 replications within a nursery bed at Penn Nursery, operated by the Pennsylvania State Bureau of Forestry.

The seedlings were raised using operational nursery practices for irrigation, fertilization, weeding and insect control. In September 1987, half of the seedlings in both radicle treatments were lateral root pruned. This was done by vertically cutting between the rows of seedlings with a sharpened spade to a depth of 25 cm. The treatment combinations resulted in 4 classes of seedlings: (1) control seedlings which were not subjected to any treatment; (2) seedlings subjected to radicle clipping or (3) lateral root pruning; and (4) seedlings subjected to both treatments. All seedlings were machine lifted from the nursery in April 1988 and held in cold storage at 2°C for one month.

Upon removal from cold storage 60 seedlings from each treatment were root pruned to a length of 20 cm and planted into pots (10 seedlings per pot) containing Promix[R] media[3]. They were held in a temperature controlled greenhouse for 5 weeks. At the conclusion of this period, several shoot and root characteristics were measured. RGC was measured as the total length or total number of new roots grown during the 5 week test period.

Shoot measurements included ground-line diameter, original shoot height, and length of the terminal flush. Leaf area was measured with a Li-Cor, Inc. 3100 Area Meter (Lincoln, Nebraska). The original root system was characterized by the number of taproots, and the number of large (proximal diameter ≥ 1 mm) lateral roots. All measurements were obtained from 60 seedlings per treatment.

Analysis of variance was used to ascertain significant treatment effects. Duncans New Multiple Range Test was used to evaluate treatment means. Correlation coefficients were calculated between RGC and the various morphological variables.

## RESULTS

Seedlings produced by spring sowing of pregerminated northern red oak acorns had mean height (23.7 cm) and diameter (5.7 mm) values which were comparable to the mean height (25.6 cm) and diameter (5.0 mm) values from a sample of fall-sown nursery-run seedlings. Both seedling populations were 1-0 stock. The radicle clipping and lateral root pruning treatments had little effect on the mean height and diameter of the seedlings at the April lifting date. The only significant effect that root treatments had on shoot size was a slight increase in stem diameter for the lateral pruned seedlings with clipped radicles (Table 1). However, root morphology was strongly affected by the treatments. The average number of taproots per seedlings was increased 4-fold by the radicle clipping while the number of coarse lateral roots was decreased significantly by this treatment (Table 1).

All measures of growth in the greenhouse were increased significantly by one or both treatments (Table 2). The 5-week height growth increment (terminal elongation) was increased over 50% by the radicle clipping treatment, whereas lateral root pruning had no significant effect. Mean leaf area was significantly greater for the combined treatment than for either single treatment or the control. Either treatment alone resulted in nonsignificant increases in leaf area.

Root growth capacity, as measured by the number or length of new roots was not increased significantly over control seedlings by either the radicle clipping or lateral pruning used singly. However, the number of new roots was doubled over control levels for seedlings which were subjected to both the radicle clipping and lateral root pruning treatments (Table 2). The length of new roots was also significantly increased by the combination clipping and pruning treatment. The strong interaction

[3] Promix[R] is a plant growth medium consisting of shredded peat moss, vermiculite, perlite and nutrient amendments.

Table 1. -- Morphological responses of northern red oak seedlings to root pruning treatments.

| Morphological Measure | Radicle not clipped: Unpruned laterals (control) | Radicle not clipped: Pruned laterals | Radicle clipped: Unpruned laterals | Radicle clipped: Pruned laterals |
|---|---|---|---|---|
| Stem diameter (mm) | 5.47 b[1] | 5.53 b | 5.86 ab | 6.12 a |
| Stem height (cm) | 23.6 a | 23.8 a | 23.0 a | 24.2 a |
| Number of taproots | 1.0 b | 1.1 b | 4.5 a | 4.2 a |
| Number of coarse laterals | 3.1 ab | 3.5 a | 2.2 b | 2.5 b |

[1] Means within a row followed by the same letter do not differ significantly at the .05 level based on Duncans New Multiple Range Test.

effect of the two treatments on RGC was highly significant ($p < .001$) based on analysis of variance.

The correlation coefficients between RGC and morphology are presented in Table 3 by radicle treatment. Among the measured responses, leaf area was most strongly correlated with RGC in both radicle clipped and unclipped seedlings. The magnitude of the r-values for the other morphological variables were very inconsistent between treatments. For unclipped seedlings the only other variable significantly correlated with RGC was the number of coarse lateral roots.

For seedlings subjected to the radicle treatment, every morphological measure except height was significantly correlated with either the number or length of new roots. Also, stem diameter was strongly correlated with new root length, whereas the number of taproots was the most strongly correlated variable with new root number.

Table 2.--Five-week greenhouse growth responses of northern red oak seedlings, by treatment.

| Growth Measure | Radicle not clipped: Unpruned laterals (control) | Radicle not clipped: Pruned laterals | Radicle clipped: Unpruned laterals | Radicle clipped: Pruned laterals |
|---|---|---|---|---|
| Number of new roots | 18.9 b[1] | 23.1 b | 24.8 b | 39.8 a |
| Length of new roots (cm) | 70.4 b | 65.1 b | 86.0 b | 130.4 a |
| Terminal elongation (cm) | 9.2 b | 9.8 b | 14.3 a | 13.9 a |
| Leaf area ($cm^2$) | 307.2 b | 317.1 b | 374.0 b | 447.7 a |

[1] Means within a row followed by the same letter do not differ significantly at the .05 level based on Duncans New Multiple Range Test.

Table 3. Correlation coefficients (r) relating number or length of new roots (root growth capacity) to selected morphological and growth measures by radicle treatment (n = 120).

| | - - - Radicle not clipped - - - | | - - - Radicle clipped - - - | |
|---|---|---|---|---|
| Measure | Number of new roots | Length of new roots | Number of new roots | Length of new roots |
| | - - - - - - - - - - - - r | - - - - - - - - - - - - | | |
| Stem diameter | NS[1] | NS | .24 **[2] | .38 *** |
| Stem height | NS | NS | NS | NS |
| Number of taproots | NS | NS | .27 ** | .26 ** |
| Number of coarse laterals | .32 *** | .32 *** | .21 * | NS |
| Terminal elongation | NS | NS | NS | .20 * |
| Leaf area | .52 *** | .50 *** | .58 *** | .60 *** |

[1] NS denotes no significant correlation at the .05 level.

[2] Asterisks denote a significant correlation at the .05 level (*), at the .01 level (**), and at the .001 level (***).

## DISCUSSION

The root pruning treatments resulted in a strong interactive effect of radicle clipping and lateral root pruning on increasing RGC. However, neither root treatment alone had a significant effect on RGC. The increase in height growth and leaf area observed in the greenhouse further suggests the possibility of improved seedling field performance by employing the two root treatments. This study indicates that large vigorous 1-0 northern red oak nursery stock can be established by spring sowing of sprouted acorns. Root pruning treatments had little effect on the height and diameter of seedlings in the nursery, but the treatments did alter root morphology. Treatment induced changes in coarse lateral root and taproot number may have been the reason for the differential growth response after planting.

To accomplish the radicle clipping treatment on a large scale, the acorns need to be sprouted before sowing, allowing the radicles to emerge approximately 1-4 cm. Sufficient radicle breakage might be obtained by vigorously shaking acorns in a container to sever the brittle radicle tips. The acorns should then be immediately sown. Lateral roots could also be pruned by using a tractor-drawn cutting disk to slice between seedling rows in the nursery bed.

In conclusion, these root pruning treatments hold promise for improving RGC, and possibly outplanting performance of bare root northern red oak nursery stock. Currently, we have studies in progress to document the outplanting performance of seedlings so treated. Also, further nursery trials are being conducted to investigate the effect of several other root pruning combinations on various seedling attributes.

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SOIL NITROGEN MINERALIZATION UNDER BLACK WALNUT

INTERPLANTED

WITH AUTUMN-OLIVE OR BLACK ALDER[1]

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Abstract.-- Seasonal changes in soil nitrogen (N) mineralization rates were estimated in situ at two locations in plots of black walnut interplanted with $N_2$-fixing autumn-olive or black alder. Soil N mineralization rates were highest in most plots at both sites in late summer. N mineralization rates in plots containing actinorhizal autumn-olive or black alder were higher throughout the growing season than in pure walnut plots. It was estimated that plots containing actinorhizal interplantings produced as much as 236 kg $ha^{-1}$ $yr^{-1}$ of net mineral N in the upper 20 cm of soil, which is higher than values previously reported for hardwood forest soils in North America. Plots containing actinorhizal interplantings produced 118 to 236 kg of net mineral N per ha per yr in the upper 20 cm of soil, compared to only 65 to 90 kg $ha^{-1}$ $yr^{-1}$ in the pure walnut plots. Plots which had high N mineralization also had the largest walnut trees. Soils at both sites were acidic (pH 4.1 and 6.5) and low in extractable P (1.4 and 0.7 mg $kg^{-1}$ dry mass). Mineralization of N proceeded through the nitrification process in all plots at both plantations throughout the growing season despite low pH and low extractable P concentrations, which are generally believed to inhibit nitrification.

## INTRODUCTION

Black walnut (*Juglans nigra* L.) is one of the more valuable timber species of the central hardwood forest region of North America. Management practices that increase the merchantable yield and quality of black walnut make it an even more attractive tree species for forest managers. Fertilization, particularly with N, is one way of achieving increased walnut growth (Phares 1973). However, N fertilization can be expensive and stimulate weed growth. One alternative is to interplant walnut with $N_2$-fixing plants that add N to the soil and help control weed competition through shading at the same time.

Woody nurse crops which are associated with $N_2$-fixing actinomycetes of the genus *Frankia* have been used to improve the growth of several hardwood species (Dawson 1986). Apart from improving N fertility, additional benefits of woody nurse crops include: wind protection; weed control; promotion of self-pruning, straighter boles, and faster height growth in crop trees; and an additional source of wood fiber (Burke and Williams 1973, Melillo and Aber 1979, Schlesinger and Williams 1984, Van

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Sambeek *et al.* 1985). Several hardwood species, including black walnut, have shown improved growth and stem form when interplanted with black alder (*Alnus glutinosa*(L.) Gaertn.) or with autumn-olive (*Elaeagnus umbellata* Thunb.) (Plass 1977, Funk *et al.* 1979, Schlesinger and Williams 1984, Van Sambeek *et al.* 1985).

Soil total N levels have been found to be higher under tree plantations containing *Frankia* and *Rhizobium*-nodulated plants than in stands lacking the $N_2$-fixing component (Tarrant 1961, Tarrant and Miller 1963, Bollen *et al.* 1967, Borman and DeBell 1981, Hansen and Dawson 1982). N accumulation rates ranging from 60 to 209 kg $ha^{-1}$ $yr^{-1}$ have been estimated on sites with *Alnus* spp. (Tarrant 1968). On sites lacking $N_2$-fixing plants there is little or no net accumulation of soil N (Dawson 1983).

However, net accumulation of soil N does not necessarily result in increased availability of N to plants. In order to estimate the amount of N that is available for plant growth, it is necessary to assay for soil N mineralization. At the Ambeer Creek site used in this study, Ponder (1980) showed that soil total N and soil $NO_3^-$-N levels were higher at one point in time under mixtures of black walnut and autumn-olive than under pure black walnut.

Friedrich and Dawson (1984) found that soils of interplantings of walnut with black locust (*Robinia pseudoacacia* L.) and autumn-olive at the Ambeer Creek site had the highest total N concentrations, followed by soils under black alder interplantings and pure walnut control plots at the same site. However, walnut basal area was not strongly correlated with soil total N concentration, suggesting that differences may exist in soil N mineralization among interplantings.

In order to further our understanding of N fertility in black walnut interplantings with actinorhizal plants, we examined seasonal $NO_3^-$-N and $NH_4^+$-N availability in actinorhizal interplantings where improved walnut growth has been reported. In so doing, we hoped to obtain a more accurate measure of the contribution of actinorhizal plants to soil N fertility in black walnut interplantings with actinorhizal (*Frankia*-nodulated) plants than has been previously obtained using soil total N measures or single samples of soil mineral N status. The specific objectives of our study were to estimate differences in N mineralization associated with site, season, and interplanted species. Additional objectives included estimating total annual N mineralization in soils of the interplantings and relating N mineralization rates to soil pH, total N, total organic C, and extractable P.

## STUDY SITES AND METHODS

Our study was conducted on the Ambeer Creek (AC) and Hogthief Creek (HC) plantations established in 1969 in southern Illinois by the United States Forest Service for the purpose of evaluating the effects of various $N_2$-fixing nurse crops on black walnut growth and stem quality. Both plantations are located on bottomland soils which had been agricultural fields in the past (table 1). Two plots each of walnut with autumn-olive, of walnut with alder, and of pure walnut (controls) were established at each site. Plots were arranged in a randomized complete block design. Within each plot 24 walnut trees were planted in 6 rows (3.7 m apart) with walnut spacings within rows of 9.8 m. Three alder trees or autumn-olive shrubs were planted at a spacing of 2.4 m between walnuts in a row, giving an overall spacing of 2.4 by 3.7 m. Border rows of pure walnut were planted around the perimeter of each plot. Weeds were controlled for the first 5 years after plantation establishment and missing trees were replaced after the second and fourth years.

Soil N mineralization was measured *in situ* using soil cores incubated in polyethylene bags (Eno 1960). In each plot, three soil cores were extracted at randomly selected points and separated into 0-10 and 10-20 cm depth increments. Intact soil cores were placed into 0.04 mm thick polyethylene bags and replaced in their original locations in the soil for an incubation period of 35 days in the spring and early summer of 1987, 60 days in late summer and fall, and 150 days over the winter of 1987-88. At the beginning of each incubation, adjacent soil cores were removed to determine the initial levels of $NH_4^+$-N and $NO_3^-$-N.

Fresh and incubated soil cores were brought to the laboratory on ice where a 5 g subsample was extracted with 75 ml of 1 N KCl for 1 hr. Samples were equilibrated overnight at 3° C and then filtered (Whatman #42 filter paper) and stored at -20° C until analysis. Filtrates were analyzed using a Wescan Ammonia Analyzer. Net N mineralization was estimated as the sum of

Table 1.--Location, edaphic characteristics and precipitation of the two plantation sites.

| | Site | |
|---|---|---|
| | Ambeer Creek(AC) | Hogthief Creek(HC) |
| County | Alexander | Hardin |
| Location | Lat.37° 14'N, Long.89° 19'W | Lat.37° 30'N, Long.88° 17'W |
| Soil | Haymond silt loam, Typic Udifluvent | Belknap silt loam, Aeric Fluvaquent |
| Soil drainage | well drained | somewhat poorly drained |
| Walnut suitability[1] | suitable | questionable |
| Mean annual precipitation[2] | 1159mm | 1165mm |
| Study period precipitation[3] | 995mm | 1146mm |

[1]Losche et. al. 1980.
[2]NOAA 1983.
[3]NOAA personal communication.

ammonification (net change in $NH_4^+$-N) and nitrification (net change in $NO_3^-$-N) for each soil sample during the incubation period.

Three additional samples were collected in each of the six plots at both sites at the 0-10 cm and 10-20 cm depths in the late summer to be analyzed for soil pH, total nitrogen (Bremner and Mulvaney 1982), extractable P (Olsen and Sommers 1982, Robarge and Fernandez 1986), total organic carbon (Nelson and Sommers 1982), and bulk density. Soil pH was measured using the 0.01 M $CaCl_2$ method described by Robarge and Fernandez (1986). Walnut survival, diameter at 1.07 m, and total height were determined after the 18th growing season during which N mineralization was measured.

## RESULTS

### Nitrogen mineralization

Seasonal variation in N mineralization occurred at both sites with most of the peak values in net N mineralization occurring in August (fig. 1). $NO_3^-$-N was the most abundant form of mineral N found in the incubated soil cores. In some cases $NO_3^-$-N yield exceeded net N mineralization due to an apparent net loss of $NH_4^+$-N during incubation of soil cores. Net loss of $NH_4^+$-N is possible when $NH_4^+$-N pools are initially large at the beginning of an incubation and nitrification proceeds faster than ammonification (Nadelhoffer et al. 1984) or where $NH_4^+$-N is immobilized in incubated cores. Net $NO_3^-$-N yields were generally high throughout the growing season in all plots.

General seasonal patterns in N mineralization were similar for the sites and interplantings studied. However, the total annual amounts of mineral N produced at the two sites and in the various interplantings differed considerably (table 2). Soils beneath autumn-olive interplantings showed the highest production of mineral N (138 to 236 kg $ha^{-1}$ $yr^{-1}$) followed by alder (118 to 185 kg $ha^{-1}$ $yr^{-1}$) then controls (65 to 90 kg $ha^{-1}$ $yr^{-1}$). Values obtained for the total annual production of mineral N in the controls were consistent with those reported in similar studies by Pastor et al. (1984) and Nadelhoffer et al. (1985) for hardwood stands in Wisconsin. Soils beneath autumn-olive and alder interplantings, particularly at AC, showed annual N mineralization levels that are higher than or at the high end of other reported values for forests and tree plantations in North America (Pastor et al. 1984, Nadelhoffer et al. 1985).

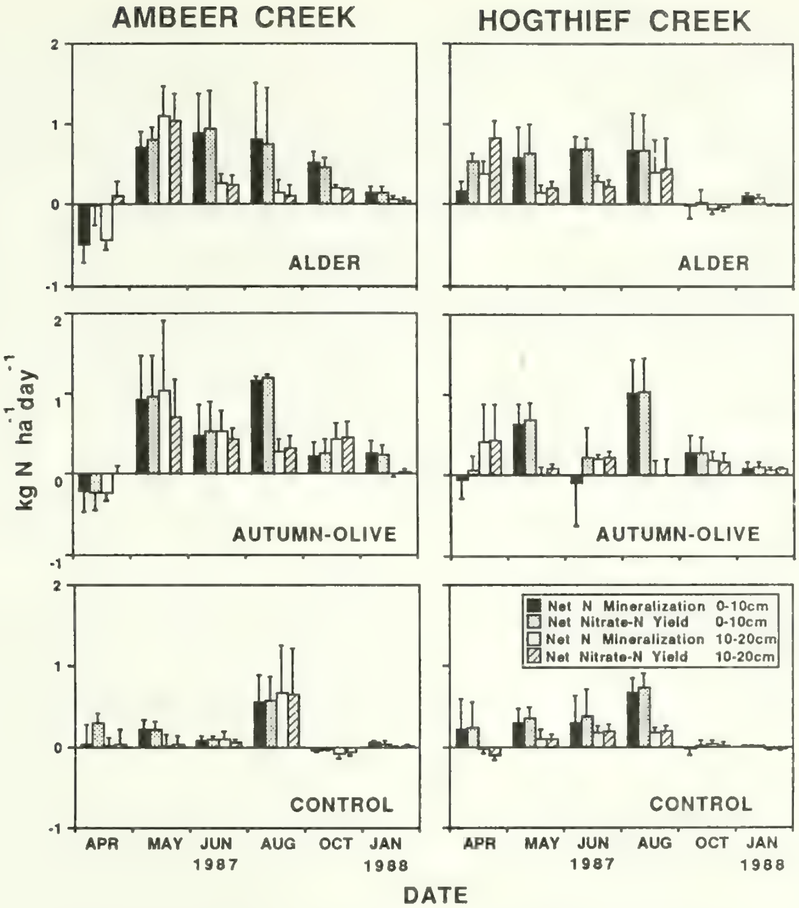


Figure 1. Seasonal patterns of soil $NH_4^+$-N and $NO_3^-$-N production in the 0-10cm and 10-20cm soil layers in black walnut plots interplanted with autumn-olive, black alder, and pure walnut plots at the Ambeer Creek (AC) and Hogthief Creek (HC) plantations (kg N $ha^{-1}$ $day^{-1}$+ 1 SE of the mean).

Table 2.--Total annual production of mineral N during the study period (kg $ha^{-1}$ $yr^{-1}$) and percentage of the soil total N pool mineralized during the 1 year experiment.

| Site | Interplanting | Depth(cm) | $NH_4^+$-N | $NO_3^-$-N | Total net mineralized N | %N Mineralized |
|---|---|---|---|---|---|---|
| AC | alder | 0-10 | -9.25 | 146.04 | 136.09 | 9.8 |
| AC | aut.-olive | 0-10 | -0.67 | 178.28 | 177.62 | 13.5 |
| AC | control | 0-10 | -9.41 | 61.00 | 51.59 | 3.3 |
| AC | alder | 10-20 | -2.55 | 51.21 | 48.66 | 4.5 |
| AC | aut.-olive | 10-20 | -10.94 | 69.45 | 58.51 | 5.8 |
| AC | control | 10-20 | -8.63 | 46.98 | 38.35 | 2.7 |
| HC | alder | 0-10 | -11.05 | 97.60 | 86.55 | 4.7 |
| HC | aut.-olive | 0-10 | -40.12 | 139.28 | 99.17 | 5.7 |
| HC | control | 0-10 | -17.13 | 73.76 | 56.63 | 2.9 |
| HC | alder | 10-20 | -13.57 | 45.22 | 31.65 | 2.6 |
| HC | aut.-olive | 10-20 | -9.28 | 48.61 | 39.33 | 3.8 |
| HC | control | 10-20 | -3.67 | 12.07 | 8.40 | 0.8 |

The percentage of the soil total N pool mineralized during the year in each plot ranged from 2.9 to 13.5% in the upper 10 cm and from 0.8 to 5.8% in the lower 10 cm (Table 2), with the highest percentages occurring in autumn-olive interplantings (7.2%), followed by alder (5.4%), then controls (2.4%).

## Walnut Growth

Black walnut growth in both 18-year-old plantations was greatest in the autumn-olive interplantings (table 3). Walnut growth was greater in the alder interplanting than in the pure walnut controls at Ambeer Creek (AC), but not at Hogthief Creek (HC). The differences between locations in the growth of walnut interplanted with alder is probably due to death of alders at HC as described by Rietveld et al. (1983). In general, the black walnut growth differences that we measured at 18 years of age follow the same patterns that Schlesinger and Williams (1984) reported at age 13 years in these same interplantings.

## Soil pH

Soil pH values indicate very slightly acid to strongly acid soils at HC, and very strongly acid soils at AC. Soils under autumn-olive interplantings were more acidic than under alder or controls at both sites (table 4).

## Soil Phosphorus

Soil extractable P levels ranged from 0.4 to 0.8 mg kg$^{-1}$ dry mass at HC and from 0.6 to 2.3 mg kg$^{-1}$ dry mass at AC (table 4). Due to the unusually low values of P found in all plots, these soils would have to be regarded as being deficient in available P (Stevenson 1986). Levels of P were highest in the 0-10 cm depth and showed little variation between interplantings, except in the autumn-olive interplantings at AC where P levels in the upper 10 cm of soil were considerably higher than in the upper 10 cm of soil in the alder interplantings or controls.

## Organic Carbon and Total Nitrogen

Soil total organic C levels varied from 13,841 to 21,836 kg ha$^{-1}$ in the upper 10 cm, and from 996 to 1403 kg ha$^{-1}$ in the lower 10 cm (table 4). Soil total N values ranged from 1317 to 1928 kg ha$^{-1}$ in the upper 10 cm and from 996 to 1403 kg ha$^{-1}$ in the 10-20 cm depth. Total N and organic C in the upper 10 cm were both higher at HC and were lowest in autumn-olive interplantings at both sites. Values for total N and organic C in the 10-20 cm depth were more uniform for interplantings and sites. C:N ratios were all low, ranging from 10:1 to 14:1 in the upper 10 cm and from 8:1 to 11:1 in the 10-20 cm layer. C:N ratios were always higher in the upper 10 cm and

Table 3.--Dimentions and estimated biomass of 18-year-old black walnut trees interplanted with alder and autumn-olive at two sites (plot means, n=2).

| Site | Interplanting | dbh(cm) | Height(m) | Mortality(%) | Total estimated walnut above-ground dry biomass[1] (kg plot$^{-1}$) |
|---|---|---|---|---|---|
| AC | alder | 14.2 | 10.1 | 9 | 1219 |
| AC | autumn-olive | 18.9 | 11.9 | 2 | 2554 |
| AC | control | 11.7 | 7.6 | 73 | 78 |
| HC | alder | 13.6 | 7.3 | 18 | 759 |
| HC | autumn-olive | 19.4 | 12.8 | 7 | 2538 |
| HC | control | 12.4 | 7.0 | 11 | 742 |

[1]biomass = $5.40056 + 0.02307d^2h$ where d = dbh(cm) and h = height(m). From Rietveld et al. 1983.

Table 4. Measured soil properties at the two study sites. Mean values and (standard errors).

| Site | Inter-planting | soil depth (cm) | n | pH | extractable P (mg $kg^{-1}$) | total N (kg $ha^{-1}$) | Organic C (kg $ha^{-1}$) | C:N |
|---|---|---|---|---|---|---|---|---|
| AC | *Alnus* | 0-10 | 6 | 4.16(0.02) | 1.0(0.2) | 1388(124) | 19715(3744) | 14 |
| AC | *Elaeagnus* | 0-10 | 6 | 3.85(0.10) | 2.3(0.5) | 1317(123) | 13841(1054) | 11 |
| AC | none | 0-10 | 6 | 4.37(0.05) | 1.0(0.1) | 1558(207) | 16114(1184) | 10 |
| AC | *Alnus* | 10-20 | 6 | 4.19(0.05) | 0.8(0.1) | 1074 (65) | 9134 (422) | 9 |
| AC | *Elaeagnus* | 10-20 | 6 | 4.19(0.08) | 1.2(0.1) | 1005 (45) | 9492 (603) | 9 |
| AC | none | 10-20 | 6 | 4.47(0.04) | 0.6(0.1) | 1403(170) | 11135 (364) | 8 |
| HC | *Alnus* | 0-10 | 6 | 6.97(0.11) | 0.8(0.1) | 1855(181) | 20523(1582) | 11 |
| HC | *Elaeagnus* | 0-10 | 6 | 5.59(0.43) | 0.6(0.1) | 1727(288) | 18268(2606) | 11 |
| HC | none | 0-10 | 6 | 6.85(0.17) | 0.8(0.1) | 1928(103) | 21836(1051) | 11 |
| HC | *Alnus* | 10-20 | 6 | 6.69(0.13) | 0.5(0.0) | 1226 (66) | 11307 (420) | 9 |
| HC | *Elaeagnus* | 10-20 | 6 | 5.29(0.29) | 0.4(0.1) | 1039(119) | 9832 (771) | 9 |
| HC | none | 10-20 | 6 | 6.21(0.24) | 0.4(0.1) | 996 (78) | 10834 (473) | 11 |

showed little variation between sites and treatments (table 4). These soil C:N ratios are at the lower end of values reported in the literature and are in a range where N mineralization would be favored.

## DISCUSSION

N mineralization was found to have seasonal pulses, indicating that sampling must be done throughout the year in order to quantify annual mineralization. Other researchers using the buried bag technique have found similar seasonal variation (Nadelhoffer *et al*. 1984, Pastor *et al*. 1984). Because N mineralization is a microbial reaction, temperature and moisture are important controlling factors. Estimated total annual production of mineral N in soils beneath these actinorhizal interplantings was high when compared to similar studies in hardwood forest stands in the temperate region of North America (Pastor *et al*. 1984, Nadelhoffer *et al*. 1985). The greater production of mineral N occurred in plots with the best walnut growth, whereas lower production of mineral N occurred in plots with poor walnut growth. This indicates a stronger relationship between walnut growth and N input into soils than has been previously reported (Friedrich and Dawson 1984). These results indicate that $N_2$-fixation is probably important in increasing walnut growth in these mixed plantings, although other benefits to walnut growth from interplanting such as weed suppression and sheltering are difficult to segregate from the effects of improved N fertility (Friedrich and Dawson 1984).

The idea that forest trees primarily take up $NH_4^+$-N, particularly in acidic soils, has been widely promoted (Keeney 1980) However, it is now known that some tree species preferentially take up $NO_3^-$-N. Studies by Krajina *et al*. (1973), Bigg and Daniel (1978), and Van den Driesche (1978) have shown that some tree species attain better growth on sites where a particular form of mineral N predominates. Our results indicate $NO_3^-$-N is the major form of mineral N available to black walnut interplanted with actinorhizal $N_2$-fixers and supports the emerging view that nitrification may be a more important process in temperate forest soils than was previously thought.

A review of the literature by Keeney (1980) indicates that many authorities assumed that the acidity of most forest soils inhibits autotrophic nitrification. Alexander (1977) reported that nitrification typically decreased below pH 6.0 and is negligible below pH 5.0, except where acid adapted strains of heterotrophic nitrifiers were present. Our observation of high nitrification rates at pH values as low as 3.85 indicates the presence of acid-tolerant nitrifiers in these plantations.

In addition to pH, P supply is believed to regulate nitrification. Purchase (1974) and Pastor *et al*. (1984) have suggested that P deficiency can restrict nitrification in forest plantations. The low soil P concentrations in late summer at both HC and AC did not seem to restrict

nitrification. The seasonal availability of P was not determined, therefore, the relationship between available P and nitrification could not be determined.

At the AC plantation, Ponder (1980) found soil total N levels in autumn-olive interplantings to be higher than in pure black walnut plots (3890 vs. 2491 kg $ha^{-1}$) at the 0-20 cm depth. Our study found soil total N levels in late summer at the 0-20 cm depth at AC to be lowest in autumn-olive interplantings (2322 kg $ha^{-1}$) and highest in pure walnut plots (2961 kg $ha^{-1}$). These discrepancies in soil total N in autumn-olive interplantings at AC could be due to analytical errors, methodological differences, or actual changes in the soil total N pool. Given the percentage of the soil total N pool estimated by us to be mineralized in the autumn-olive interplanting during the year of our study, it seems that the latter is true. Of the soil total N pool, 7.2% was mineralized in one year in the upper 20cm of the autumn-olive interplantings as compared to 5.4% in one year for alder and 2.4% for pure walnut in our study. Thus the soil total N pool in the actinorhizal interplantings may be declining faster than the soil total N pool in the control plots - suggesting that the input of N-rich litter from actinorhizal plants may have a priming effect on N mineralization. Although these N mineralization percentages are high, we feel that they are not unreasonable given the low C:N ratios. It should also be noted that the N content of litter is not included in the soil total N estimates. The turnover of N rich litter from the actinorhizal interplantings could also have resulted in the high values obtained for net N mineralization as a percentage of the soil total N pool where the litter component is excluded.

In the alder interplantings at HC $N_2$-fixation most likely ceased after plantation age 13 due to extensive alder mortality (Rietveld et al., 1983); however, mineralization rates at plantation age 18 are still higher for mixed alder plots than for controls.

Apparently, soil total N pools had been built up over a number of years by N inputs exceeding mineralization. In recent years the inputs in the autumn-olive interplantings and alder interplantings, where alder mortality is high, may have decreased even as high N mineralization rates occurred, thus reducing the soil total N pools to levels comparable to the controls.

The component of black walnut growth improvement due to increased availability of mineral N in the autumn-olive interplantings will probably decline in the future although the benefits of $N_2$-fixation and interplanting are likely to extend well beyond the life of the autumn-olive. Alder trees not killed by black walnut's allelochemical juglone have growth rates comparable to black walnut on these sites and should continue to provide N to the walnut trees. However, the benefits of improved N fertility afforded by alder trees are probably offset to some extent by their competition with walnut for light, water and nutrients.

In summary, we have shown annual N mineralization rates to be high in mixed plantings of black walnut with actinorhizal plants. Net $NO_3^-$-N production far exceeded the yield of $NH_4^+$-N, even though soil pH and soil available P were low. Mineralization rates varied seasonally and annual rates were highest in the autumn-olive interplantings where the largest walnut trees also occurred. These results confirm the importance of N input from $N_2$-fixing actinorhizal plants in promoting black walnut growth. They also illustrate the complexity of relationships of actinorhizal plant development and mortality with soil N mineralization.

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THE IMPORTANCE OF BELOW GROUND INTERACTIONS FOR HARDWOOD GROWTH [1]

Felix Ponder, Jr. [2]

Abstract--Interfering plants can seriously impede regeneration efforts under some site and forest conditions. Nutrient release, nutrient accumulation, and microbial activity may, however, be enhanced depending on the plants, their associated underground activity, and the microorganisms involved. Most of the mechanisms by which the microbiota affects higher plants are yet to be established.

## INTRODUCTION

Studies of competition between trees and unwanted vegetation and among trees themselves usually involve above ground factors such as light, space, and carbon dioxide and below ground factors such as water, nutrient elements, and oxygen. Interactions between microorganisms, their substrate, mineral sources, and plant-produced chemicals are rarely considered.

Soil character, including "available" soil fertility, results from interactions between plant constituents and soil microbiota. The nature and results of these interactions are influenced primarily by the availability of nutrient elements to plants and of energy to microorganisms. The supply of these resources, in turn, influences plant productivity.

Most of the important below ground activity takes place on and around the root system (rhizosphere activity). The rhizosphere is not a uniform, well-defined region but a zone with a microbial gradient extending from the root surface to soil a centimeter or two surrounding the root. Many compounds are both taken up and released in this region.

The purpose of this paper is to review information on competition associated with nutrient element availability and allelopathy, in soils beneath hardwoods and to suggest areas where more research is needed. Data and discussion in this review center on soil activity within the tree-root influence but are not limited to the rhizosphere.

### Nutrient Availability

The growth benefits afforded non-nitrogen-fixing plants when grown in mixture with nitrogen-fixing plants are well documented (Ashby and Baker 1968, Funk _et al_. 1979, Haines and DeBell 1979). Growth enhancement is attributed to reduced grassy competition and cooler temperatures (Dawson and Funk 1981, Funk _et al_. 1979), but mostly to biologically fixed nitrogen and the increase of nitrate nitrogen ($NO_3$-N) in the soil (Ike and Stone 1958, Finn 1953, DeBell and Radwan 1979). In a 10-year-old mixed planting of black walnut (_Juglan nigra_ L.) and autumn olive (_Elaeagnus umbellata_ Thumb.), only $NO_3$-N of all measured soil nutrient elements increased (Ponder _et al_. 1980).

Nitrogen nutrition explains only part of the better growth of walnut planted in mixtures. In a study of plots that included European alder (_Alnus glutinosa_ (L.) Gaertn.) mixed with walnut in addition to plots of autumn olive/walnut and walnut alone, soil samples were analyzed for available potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), and sodium (Na). The amount of Cu and Na did not differ between treatments, but the mean K and Ca concentrations did. Potassium was highest in soils from autumn olive/walnut plots and lowest in walnut alone plots. At the 60 cm soil depth 0.9 m from the walnut trees, autumn olive/walnut plots contained nearly twice as much K as European alder/walnut plots. Calcium was highest in autumn olive/walnut plots; it did not differ between European alder/walnut and walnut alone plots. Both Mg and Zn were highest in European alder/walnut plots. The mean concentration of Mg in autumn olive/walnut plots was intermediate between plots of European alder/walnut and walnut alone. Zinc concentrations were similar in autumn olive/walnut and walnut alone plots.

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Changes in nutrient concentrations within the soil of the various treatments cannot be readily explained but are believed to be associated with microorganisms in the rhizosphere and on the roots themselves. Particularly important are the mycorrhizae. For example, where ammonium nitrogen ($NH_4^+$-N) is the primary source of N, the mycorrhizae increase the competitive uptake by higher plants for $NH_4^+$-N (Raven et al. 1978). Mycorrhizae do this by converting $NH_4^+$-N to glutamine, which moves from the mycorrhizal fungi to the plant for uptake. The hydrogen ion (H+) produced by the assimilation of the $NH_4^+$-N is excreted by the fungus to obtain more $NH_4^+$-N in competition with other microorganisms. The excreted H+ may produce pH changes that may further affect nutrient availability.

Thus it may be concluded that part of the explanation for the modified growth of black walnut or other trees in mixtures compared with pure stands is to be found in the interactions between roots, other organic substrates, invertebrates, and microorganisms in the soil and litter. This in no way diminishes the importance of symbiotically fixed nitrogen in mixed culture.

The roots of some plants have adaptive mechanisms for taking up nutrients in short supply (Atwill 1986). Mulette et al. (1974) showed that eucalyptus (Eucalyptus gummifera (Gaertn.), Hochr.) seedlings, regardless of their mycorrhizal condition, could get phosphorus from highly insoluble iron and aluminum phosphates. Gardner et al. (1983) showed that roots of a lupin secrete acid citrate, which solubilizes iron phosphate. Yet to be defined are the mechanisms by which some trees can extract and accumulate large amounts of specific nutrient elements such as calcium in the oaks (Weaver and Jones 1987).

## Nitrifying Bacteria

Many hardwoods produce phytotoxins (Kuiters and Sarink 1986). Most notorious among allelopathic chemicals is juglone, which is produced by black walnut and members of the walnut family. Juglone and most of the other phytotoxins of concern in regeneration are phenolic compounds. In cases where phytotoxins occur, nitrification may be inhibited (Atwill 1986). Rice (1964, 1965) found that many of the plants in old-field succession contained phenolic substances that were very inhibitory to nitrogen-fixing and nitrifying bacteria. Therefore, such substances may reduce nitrifying bacteria populations in walnut plantings.

Two kinds of bacteria of concern are Nitrosomonas and Nitrobacter. Soil samples were collected from the 0-8 cm soil layer 0.9 m from walnut trees. Data showed mean mid-November juglone level in a mixed planting to be highest in European alder/walnut and walnut alone plots and lowest in autumn olive/walnut plots (Ponder and Tadros 1985). With this information on juglone concentrations as a background, the most-probable-number technique was used to determine nitrifying bacteria counts. Counts were highest in European alder/walnut plots, followed by autumn olive/walnut, and walnut alone plots. Nitrate nitrogen was found to be highest in European alder/walnut plots, followed by autumn olive/walnut, and walnut alone plots. Because $NO_3^-$-N levels, which are never static and may not represent mineralization of nitrogen, and juglone concentration were both highest in European alder plots, juglone was not inhibiting nitrification. But, why the higher counts of nitrifying bacteria in both types of mixed plots?

The dominant vegetation in walnut plots without alder or autumn olive was broomsedge (Andropogon virginicus L.). European alder/walnut plots were undergoing vegetational change due to the decline and death of European alder; autumn olive/walnut plots were developing a forest-like understory. Lodhi (1978) reported that the number of Nitrosomonas and Nitrobacter showed a direct relationship with amounts of nitrate nitrogen. Nitrosomonas and Nitrobacter increased by 18 and 34 times, respectively, after a forest clearcut in Connecticut (Smith et al. 1968). It appears that the differences in the amount of available substrate that can be utilized by the bacteria account for the differences in the number of bacteria between treatments. The vegetational change is probably responsible for the overall higher nitrifying bacteria counts in European alder/walnut plots.

Specific inhibition of nitrification in the field is not always observed. For example, Chandler (1985) found no inhibition of nitrification by phenolic or by leaf litter extracts in Malaysian forest soils. Robertson and Vitousek (1981) found no evidence in favor of the hypothesis that increasing levels of allelochemicals inhibit nitrification during either a primary or a secondary succession in the North Central and Northeastern United States.

The use of nitrification inhibitors that block the nitrification pathway is a way of affecting nitrifying bacteria. The chemical inhibitor suppresses the activity of the nitrifying bacteria, preventing the conversion of $NH_4^+$-N to $NO_3^-$-N. Because $NH_4^+$-N is slowly leached and relatively immobile in the soil compared to $NO_3^-$-N, preventing the conversion should increase the overall nitrogen utilization. However, because proportionately more $NH_4^+$-N than $NO_3^-$-N may be available for uptake, plant growth response will likely depend on the plant's nitrogen preference.

The survival and growth of white ash (Fraxinus americana L.), white oak (Quercus alba L.), and black walnut seedlings were investigated using the nitrification inhibitor, N-serve, (2-chloro-6[trichloromethyl]pyridine) in an old field planting. Before planting, a fescue (Festuca arundinaceae Schreb.) sod had been

rototilled the previous fall and again in the spring. Plots were designated to receive or not to receive N-serve. N-serve was applied at a rate of 1.5 Kg/ha and raked into the upper 4-cm soil layer before 1-year-old seedlings were planted. N-serve was reapplied the following spring and mixed into the upper soil layer with a garden tiller. Weeds were controlled by hoeing the first year and by a combination of hoeing and one application of Roundup the second year.

Seedlings treated with N-serve survived much better than untreated seedlings for all three species, with improvements of 28, 15, and 10 percent, respectively, for ash, oak, and walnut. After 3 years of growth, however, only the white oak had greater height and diameter growth in N-serve treated plots. Nitrate nitrogen levels were lower in N-serve plots than in control plots, indicating that the inhibitor did affect the conversion of $NH_4^+$-N to $NO_3^-$-N. Both ash and walnut grew better without N-serve. Although the preliminary results suggest that young oaks may grow better with $NH_4^+$-N rather than $NO_3^-$-N (Auchmoody 1982), further research is needed before making conclusions on N preference for oak.

## Allelopathy

Competition due to allelopathy has been demonstrated in several greenhouse studies (Gilmore 1980, Larson and Schwarz 1980, Patrick 1971). Allelopathy in forest stands has been much harder to prove because of the fewer controls over environmental conditions such as moisture, temperature, and competition (Rietveld _at al_. 1983, Rink and Van Sambeek 1985). The allelopathic effects of plants can sometimes be detected by their influence on the mineral uptake of their associates (Balke 1985). This was demonstrated in a study investigating the effects of three weeds commonly found in walnut plantings (Ponder 1986). Foliage litter of tall fescue, broomsedge, or blackberry (_Rubus allegheniensis_ T. Porter) was either incorporated or not in plots with seeded black walnut. Of the three weed species tested, unincorporated and incorporated broomsedge litter significantly reduced total dry weight below that of the control seedlings. The total dry weight of seedlings with incorporated fescue was greatly reduced considerably whereas phosphorus content was not.

The mean absorption of N but not P by seedlings in soil with incorporated broomsedge litter was reduced considerably. Nitrogen, phosphorus, and potassium were also reduced in seedlings grown with incorporated fescue. In another experiment using the extracts of these weeds, both N and P absorption were reduced in seedlings grown with fescue extract, but only N was reduced in seedlings grown with broomsedge extract. We can, therefore, assume that these plant materials act in some way in the soil to reduce either the availability or the uptake of nutrient elements by the plant. Horsley (1986) was able to significantly increase the growth of black cherry (_Prunus serotina_ Ehrh.) seedlings in an orchard soil previously dominated by grasses and forbs only when $NO_3^-$-N, P, and Ca were applied repeatedly. From this he concluded that an inhibitory molecule may compete with a soil colloid to render nutrient elements unavailable for uptake.

Kolesnichenko and Aleikena (1976) reported that absorption of minerals from soil was lower in oak roots (_Quercus robur_ L.) growing close to ash (_Fraxinus excelsior_ L.) than in oak roots growing near other oak roots. In the laboratory, the uptake of minerals by oak roots was inhibited by chemical compounds from ash.

The inhibitory constituents of plant materials might be bound by the soil and used as carbon sources by soil microorganisms. We know in the case of some herbaceous weeds that removing the weeds significantly reduces the inhibitory effect. In a 10-year-old plantation in southern Illinois, elimination of a fescue sod understory by annual cultivation for 5 years produced trees that were 69 percent larger in diameter at age 15 than those in untreated areas. In a 17-year-old planting, Schlesinger and Van Sambeek (1986) found that eliminating fescue sod or establishing hairy vetch (_Vicia villosa_ Roth.) among the walnut trees resulted in a 250-percent increase in diameter 3 years later. The response to cultivation seems to be more than just a response to nutrient element availability and organic matter added to the soil by incorporating fescue and broomsedge because such a response would not continue for 5 years. At least part of the response to eliminating the fescue sod seems to be a function of eliminating allelopathic plants.

In some instances allelochemicals appear to accumulate in the soil over a period of years so that even when the inhibitory plants are removed, seedlings on the site continued to grow poorly (Gabriel 1965). This is believed to be the condition in some orchard stands in the Northeastern United States (Horsley 1986). In well-aerated soils organic chemical residues are normally metabolized by indigenous soil microorganisms. Conditions such as imperfect soil drainage, high soil acidity, low soil organic matter content, and residual plant parts in the soil increase the time needed for the inhibitory effects to disappear (Rietveld _et al_. 1983).

Much less is known about possible allelopathic interference from herbaceous vegetation on the development of mycorrhizal fungi that colonize the roots of forest trees (Rice 1979). The number of mycorrhizal-infected root segments of black walnut seedlings grown in mixture with unincorporated litters of fescue, blackberry, or broomsedge was more than twice the number of infected root segments of seedlings grown with incorporated litter. Poor mycorrhizal colonization was reported for _Populus_ spp. cuttings

planted on an old-field site in Iowa (Walker et al. 1982). The effects of plants within tree stands on mycorrhizal development have not been studied.

### Root Competition

The extent of a tree's roots determines the region in which it may influence the roots of its neighbors. A root system may be restricted by such factors as shallow soils, fragipans, and moisture, in addition to competition from its neighbors. Very little has been done to substantiate and explain competition in forest stands in the soil root interface. Much of what we know has been adapted from various grasses and legumes either separate or in mixtures (Vallis 1978, Wit et al. 1965, Werner 1979).

Root restriction often causes more intensive permeation of the soil by the roots and consequently more complete utilization of the available soil. Tree species that are genetically capable of producing more root tips or more fibrous roots than other species have a site adaptative advantage, especially on shallow soils, over species that lack these characteristics. On deep soils, both shallow- and deep-rooting species may coexist whereby the deep-rooted species would be forced to use nutrients from deeper soil layers; this would not be the case in monoculture (Berendse 1982). Two species may have different competitive abilities in different parts of the soil, which may mean exposure to different microhabitats, nitrogen compounds, and element concentrations. Much more needs to be learned about the seasonality of root growth, competition-induced changes of the shoot-to-root ratio, and phenotypic responses of root activity.

## CONCLUSION

To improve tree growth, we need to better understand the mechanisms that enable roots of some plants to compete better than others for growth substances. This information will provide a scientific basis for predicting changes in composition, growth, position of dominance, and response to silvicultural practice as trees mature. To obtain such information far more attention must be devoted to the biological, chemical, and physical processes that go on below ground, especially in the rooting zone.

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SEASONAL CHANGES IN NITROGEN FIXATION ACTIVITY OF

EUROPEAN BLACK ALDER AND RUSSIAN OLIVE[1]

Stephen F. Zitzer, Jeffrey O. Dawson
and George Z. Gertner[2]

Abstract.--Maximum rates of midday nitrogenase activity (acetylene-reduction) of 15 to 20 umoles $C_2H_4$ per g dry nodule per h were maintained for approximately 150 days for black alder. The seasonal length of maximum activity was similar for Russian olive, although specific nitrogenase rates were 25% lower. Nitrogenase activity increased exponentially between 10°C and 20 to 25°C for black alder and Russian olive with $r^2$ values of 27 to 73. No net hydrogen evolution by nodules was detected at any time during the assay period indicating efficient hydrogenase systems operating in nodules of alder and Russian olive under the conditions of this field assay. Alder trees were nodulated and had similar specific rates of nitrogen fixation in both upland and bottomland soils, though growth rate of alders was better on the bottomland site. In contrast, Russian olive grew best on the upland site, but nodulated roots were found only on the bottomland site.

## INTRODUCTION

Actinorhizal plants form symbiotic root nodules with filamentous soil bacteria of the genus Frankia (Callaham et al. 1978). These procaryotic microsymbionts are capable of fixing atmospheric nitrogen by reducing dinitrogen from air to two ammonia molecules which can be assimilated by bacteria and plants. The reaction is catalyzed in nitrogen-fixing bacteria by the nitrogenase enzyme complex and can be quantified using acetylene reduction assays. Root nodules may provide up to 70% of the total nitrogen assimilated by actinorhizal plants (Tripp et al. 1979), and this nitrogen becomes available to other plants through the decomposition in soil of plant litter, roots and exudates from nitrogen-fixing plants.

Seasonal changes in nitrogenase activity frequently occur in temperate regions (Pizelle 1984); thus, the amount of nitrogen fixed will depend on these seasonal patterns. There may also be seasonal changes in the hydrogenase activities of the nitrogenase enzyme complex (Roelofson and Akkermans 1979), especially in hydrogenase efficiency which is defined as the relative amount of the total electron flow through the nitrogenase complex that is not lost via reduction of protons to $H_2$ (Winter and Burris 1976). Most Frankia species examined have uptake hydrogenases capable of oxidizing $H_2$ so that the energy is available for dinitrogen reduction and is not lost to proton reduction, measured as $H_2$ evolution. Actinorhizal nodules which evolve no hydrogen during nitrogen fixation and are 100% efficient at recycling hydrogen. Some recent research has shown that there are seasonal differences in patterns of nitrogenase activity and hydrogenase activity, suggesting that these activities are not controlled by the same regulatory system (Hafeez et al. 1984, Sellstedt et al. 1986).

Because of their ability to increase available nitrogen in soils (Paschke et al. in press), actinorhizal trees and shrubs are interplanted with other tree crops, such as black walnut, to increase their growth and yield (Dawson 1986).

The primary objectives of our research were to determine if seasonal patterns of nitrogenase and hydrogenase activity occur in alder and Russian olive root nodules, and to determine if their activities are related to soil moisture and temperature changes. A secondary objective was to describe nodulation of actinorhizal plants in this planting.

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[1]Paper presented at the Seventh Central Hardwood Forest Conference, Carbondale, Illinois, March 5-8, 1989.

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## METHODS AND SITE DESCRIPTION

Two experimental interplantings of black walnut (Juglans nigra) with actinorhizal black alder (Alnus glutinosa) and Russian olive (Elaeagnus angustifolia) were established in 1978 by the U.S. Forest Service North Central Forest Experiment Station in cooperation with the Macon County Conservation District (Van Sambeek et al. 1985). Plantings were located on bottomland and upland sites in east central Illinois (89° 01' west, 39° 50' north). Their establishment, survival, growth and impact on interplanted black walnut through 1984 have been previously described (Van Sambeek et al. 1985). The experimental design was a randomized complete block. There were four replicate blocks of five plots each on each site. Pure black walnut plots were planted as controls with 42 plants per plot. Each plot was 18 x 21 m with 3 m between rows and trees within rows. In two plots of each block, the nitrogen-fixing plants were alternated with the black walnut to give 21 nitrogen fixing plants and 21 black walnut per plot.

In the initial planting during the spring of 1978, the black alder seedlings planted were one-year-old rooted cuttings from three slow-growing clones. Significant mortality occurred by the end of the first year. Subsequent replacement plantings up to the spring of 1981 were ade with 1-0 nursery-grown seedlings from the Indiana State Tree Nursery. Russian olive plantings and replantings up to 1981 were also made with 1-0 nursery-grown seedlings from a North Dakota and a Tennessee tree nursery. Thus, by the spring of 1985 when we started sampling, plant ages, including walnut ages, on both sites varied from four to seven years.

The bottomland site had been in agricultural use prior to 1978, and no additional site preparation was done before planting the trees. It was a level site on the floodplain of the Sangamon river. The soil was in the Lawson series, a fine silty mixed mesic Cumulic Hapludoll (Carroll County Soil Survey 1975). The A horizon had a silt loam texture and was 1.4 m thick directly overlying the massive alkaline silt loam C horizon. We determined that the mean pH and total nitrogen concentration (Kjeldahl) of the top 15 cm were 6.80 ±0.12 and 0.136% ±0.004% N.

The Lawson series is somewhat poorly drained, i.e., being wet for significant periods but not all the time. Available water was very high, 0.20 to 0.24 inches of water per inch of soil. Permeability of this soil is typically slow, 0.6 to 2.0 inches per hour, but on this site mottling, which indicates poor drainage, did not occur above a depth of 1.1 m.

The upland site had been a red clover-brome grass pasture prior to 1978. It is located approximately 3 km southeast of the bottomland site. The soil was in the Birkbeck series, which is in the fine silty mixed mesic Typic Hapludalf family (Champaign County Soil Survey 1982). It formed in about 120 cm of wind deposited loess over alkaline loamy glacial till. The site sloped 2 to 4% towards the northeast. The A horizon was about 30 cm thick with a silt loam texture. The B horizon had a pedogenic accumulation of clay which resulted in a silty clay loam texture to a depth of 1.2 m. The mean pH and total nitrogen concentration (Kjeldahl) of the top 15 cm were 5.41 ±0.24 and 0.124 ±0.014% N respectively.

The Birkbeck soil series is moderately well drained having a slowly permeable layer within the lower B horizon, i.e., at a depth of about 95 cm. The A, B and C horizons were all slowly permeable, though decreasing from 2.0 to 0.6 inches of water per hour from the A to the C horizon. Available water was very high in the A horizon, 0.22 to 0.24 inches of water per inch of soil. The B and C horizons had slightly less available water, 0.22 to 0.14, because of their higher clay contents and greater bulk densities compared to the A horizon. Mottling occurred at a depth of 65 cm, about in the middle of the B horizon.

Crown volumes of actinorhizal trees and shrubs were estimated using geometric approximations of crown shape for each species in order to assess relative growth success. Nitrogenase activity and net $H_2$ evolution of actinorhizal plants were measured at two to three week intervals starting before bud break on March 24, and ending 246 days later on November 23 after severe frost had killed all remaining leaves.

Each sampling day three actinorhizal trees of one species at one location were randomly chosen, and five randomly-selected samples of nodules plus control pieces of non-nodulated roots were assayed for each tree. Sampling was without replacement, so no trees were sampled more than once during the course of the study. Nodules were collected from the surficial 15 cm of the soil. The number of infection sites (nodules) per assay varied from one to 16 and averaged about four. Nodule dry weights per assay varied from 0.1 to 2.0 g and averaged about 0.75 g. The nodules, attached to 3 cm of root, were excised and were placed in 50-ml syringes, sealed, and buried in the soil at a depth of 10-20 cm. The incubation period was between 1200 h and 1300 h on any given sample day. Soil, incubation vessel, and air temperatures were recorded. Initially, the nodules and 3-cm control root samples in were incubated in air inside the buried syringes, and after an hour 10-ml gas samples were collected and stored in 12 ml-vacutainer tubes. These samples were later analyzed on an Aerograph Master A100 gas chromatograph for net $H_2$ production. The lower limit for $H_2$ detection on this machine was 0.01 umol per ml sample injection volume.

Immediately after sample collection for $H_2$ analysis, 5 ml air and 5 ml $C_2H_2$ were added to the syringes, and they were reburied and incubated for another hour to determine nitrogenase activity. In some cases, assays were allowed to run an additional hour to determine the length of linearity of the nitrogenase activity. After collection and storage of 10-ml acetylene-incubation samples in 12-ml vacutainer tubes, $C_2H_4$ production was determined with a Packard 433 gas chromatograph. The lower limit for $C_2H_4$ detection was 0.04 nmol per ml sample injection volume.

The nodules were washed, oven dried at 70° for 24 hours, and weighed. Soil from the upper 15 cm was also collected, and soil moisture determined from three replicate 1 kg samples. Soil pH was determined with a glass electrode in 1:1 soil to water ratio totaling 100 g with soil subsampled from that used to determine moisture content.

Analysis of variance and least significant differences for seasonal measurements of nitrogenase activity (umol $C_2H_4$ per g dry nodule per hr) were calculated for both sites and species. Nitrogenase activity was plotted and fit to regression curves as a function of soil temperature and soil moisture percentage.

## RESULTS AND DISCUSSION

Black alder crown volumes averaged about 140 $m^3$ for black alder on the bottomland site, which was about 140 and 190 percent greater than the crown volumes for Russian olive and pure walnut, respectively. Russian olive on the upland site had the largest mean crown volume of about 110 $m^3$. Upland alder and walnut crown volumes were much smaller than the upland Russian olive as well as their counterparts on the bottomland site. Crown competition was not yet occuring among interplanted trees and shrubs in the study plots.

All plants were abundantly nodulated except for the Russian olive plants in the upland Hapludalf soil. Extensive excavation indicated that nodulation was extremely sparse on roots of upland Russian olive, precluding measurements of nodular activity.

There is a major difference between the two soils in surficial pH, with the upland soil being more acidic than the bottomland soil. The pH of the top 15 cm of the upland A horizon was significantly more acidic than the bottomland surface soil in agreement with soil descriptions. In contrast, the Lawson series is near neutral throughout the solum and C horizon. *Frankia* isolates are generally more infective at neutral pH values (Knowlton and Dawson 1983). This may account for differences in nodulation, but pot studies that we have performed show little difference in the infective capacity of upland and bottomland soils for Russian olive.

Midday acetylene-reduction rates of 15 to 20 umoles $C_2H_4$ per g dry nodule per h were maintained for approximately 150 days for black alder (Figures 2 and 3). The length of maximum activity was similar for Russian olive nodules, though specific rates were less than 75% those of black alder (Figure 1). Nitrogenase activity of black alder nodules was detected two to three weeks after the March 19 bud break when soil temperatures exceeded 7°C. Initial detection of nitrogenase activity in Russian olive nodules coincided with an April 6 budbreak at soil temperatures exceeding 12°C. Nitrogenase activity for both species declined sharply in late September, but low levels of activity continued into November. Nitrogenase activity increased exponentially between 10°C and 20 to 25°C for black alder and Russian olive with $r^2$ values of 27 to 73 (Figures 4, 5 and 6).

Lower seasonal rates of acetylene reduction by Russian olive nodules were probably due to the greater percentage of necrotic nodule tissue of Russian olive plants. A higher percentage of necrotic tissue was consistently found in Russian olive nodules compared with alder nodules. For correlation measurements we adjusted specific rates of acetylene-reduction activity so that only functional nodule tissue was included in the nodule dry weight determination. The necrosis of nodule tissue from the bottomland site and apparent lack of nodulation of plants in upland soils suggest that Russian olive may be able to reduce its own nodulation with increased plant size, because the larger, more mature plants on the upland site lacked nodules even though the upland soil was capable of nodulating Russian olive seedlings in a pot study. Alternatively, it is possible that the symbiotic relationship is not optimal between Russian olive and *Frankia* in this locale, or that annual turnover of nodular tissue occurs to a greater extent in Russian olive than in black alder. This last idea is consistent with the increase in specific nitrogen-fixation activity during the course of the growing season that occurred for Russian olive (Figure 1).

Nitrogenase activity declined linearly with values of soil water percentage between 10 and 30% (Figures 7, 8 and 9), though the correlation was not as strong ($r^2$ values of 6 to 17), and moister soil periods in spring and early fall also corresponded with lower soil temperatures. Neither the amount of nitrogen fixed by this symbiotic system, nor the amount that becomes available to other plants in soil can be reliably estimated using the enzyme assays employed in this study. Methods described by Paschke and coworkers (in press) and by Van Sambeek and others (1985) can be applied to estimate increases in available nitrogen in soil and tissue nitrogen attributable to interplanted actinorhizal plants.

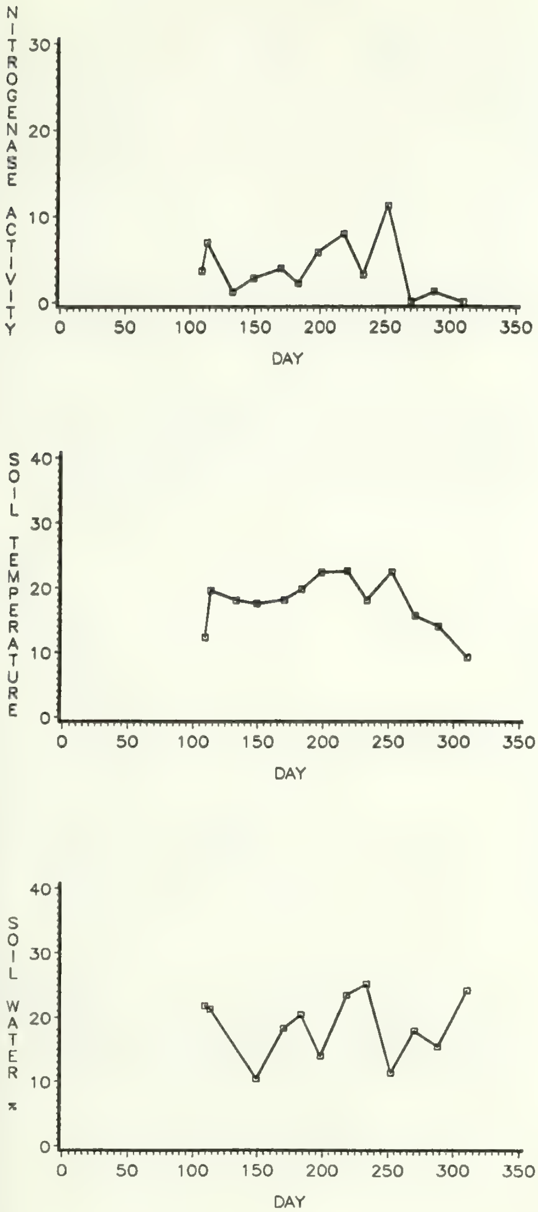


Figure 1. Seasonal pattern for nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h), soil temperature (C) and soil moisture percent associated with root nodules of Russian olive growing on a bottomland site in central Illinois. Least Significant Difference (alpha= 0.05) is 4.31 umoles $C_2H_4$ per g per h for nitrogenase activity.

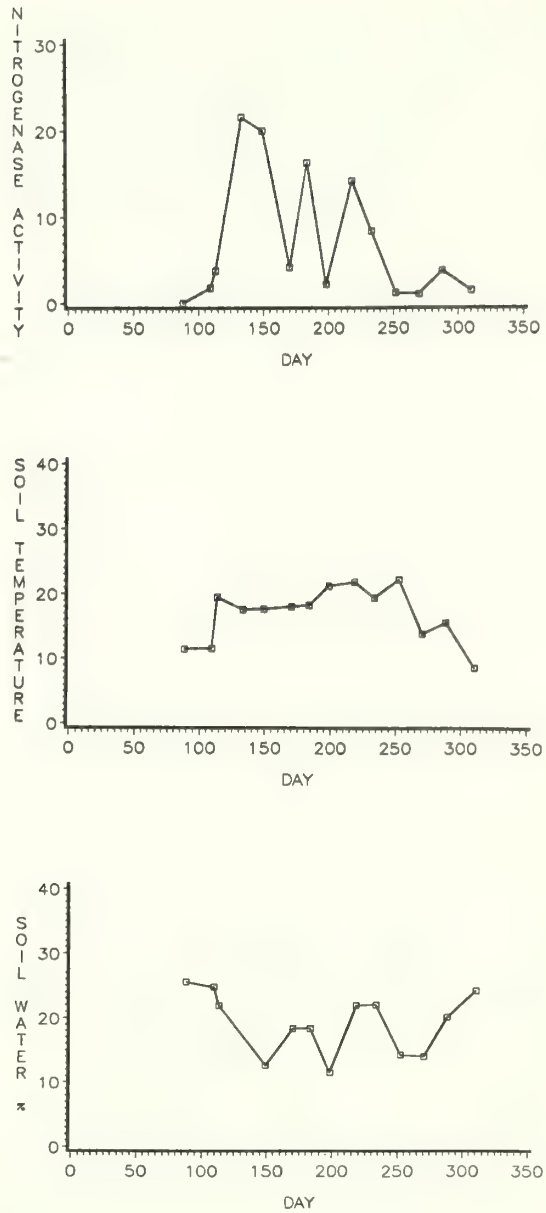


Figure 2. Seasonal pattern for nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h), soil temperature (C) and soil moisture percent associated with root nodules of black alder growing on a bottomland site in central Illinois. Least Significant Difference (alpha= 0.05) is 4.86 umoles $C_2H_4$ per g per h for nitrogenase activity.

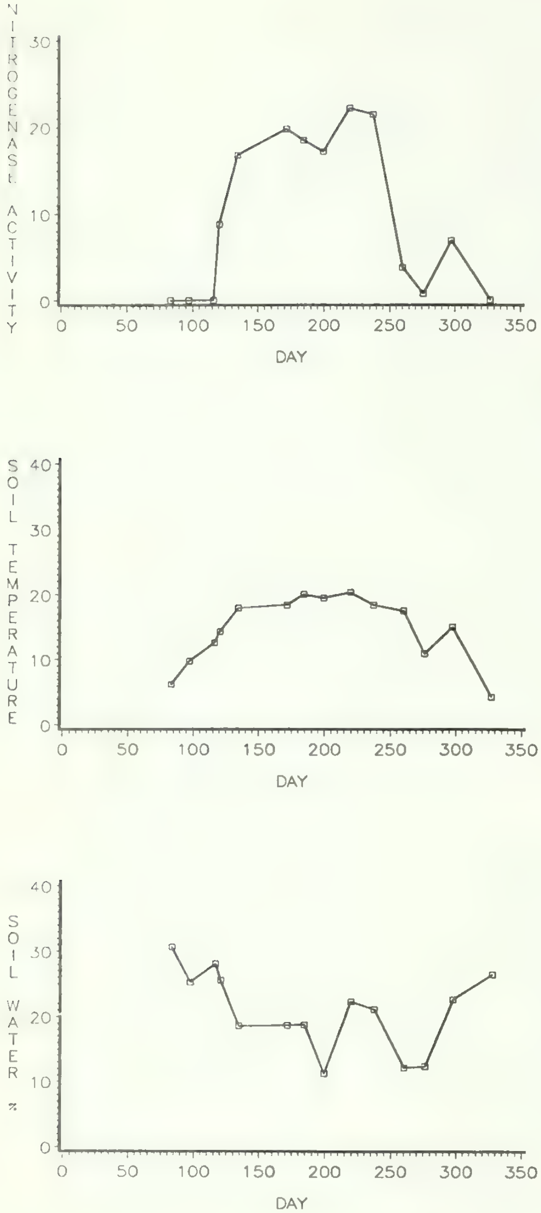


Figure 3. Seasonal pattern for nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h), soil temperature (C) and soil moisture percent associated with root nodules of black alder growing on an upland site in central Illinois. Least Significant Difference (alpha= 0.05) is 5.12 umoles $C_2H_4$ per g per h for nitrogenase activity.

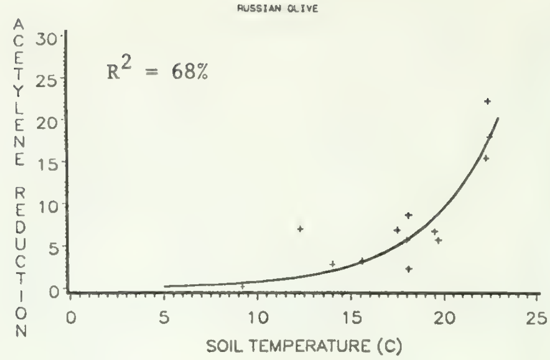


Figure 4. Relationship between soil temperature and nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h) in root nodules of Russian olive growing on a bottomland site in central Illinois.

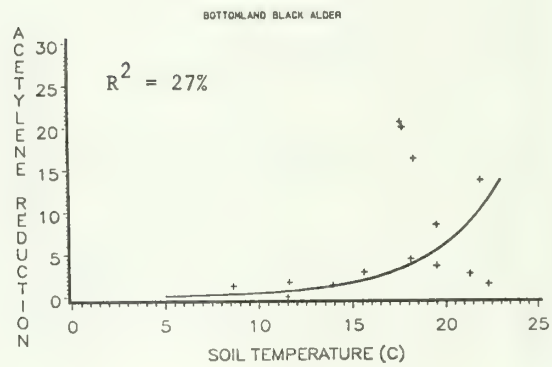


Figure 5. Relationship between soil temperature and nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h) in root nodules of black alder growing on a bottomland site in central Illinois.

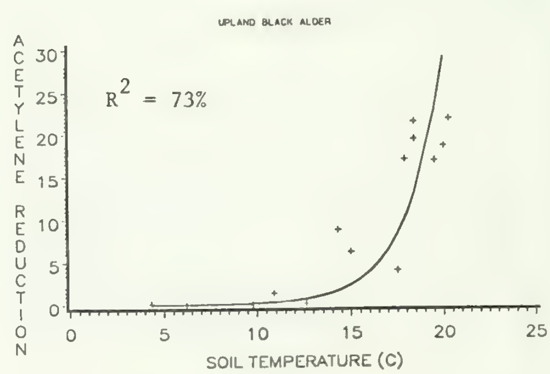


Figure 6. Relationship between soil temperature and nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h) in root nodules of black alder growing on an upland site in central Illinois.

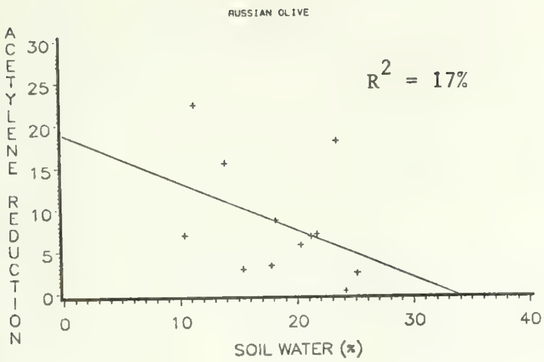


Figure 7. Relationship between soil water percentage and nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h) in root nodules of Russian olive growing on a bottomland site in central Illinois.

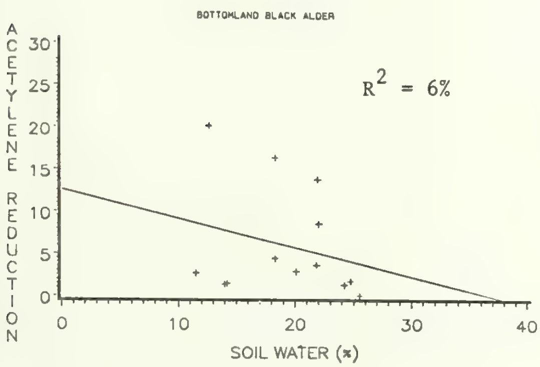


Figure 8. Relationship between soil water percentage and nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h) in root nodules of black alder growing on a bottomland site in central Illinois.

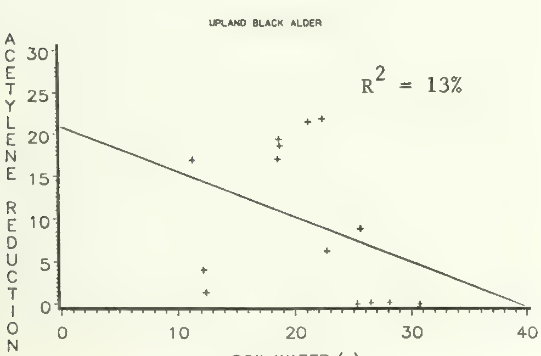


Figure 9. Relationship between soil water percentage and nitrogenase activity (umoles $C_2H_4$ per g dry wt. per h) in root nodules of black alder growing on an upland site in central Illinois.

No net hydrogen evolution by nodules was detected at any time during the assay period, and net hydrogen uptake was measured once by incubating black alder nodules in 10% $H_2$ (unpublished data). This indicates that efficient hydrogenase systems are operating in nodules of alder and Russian olive under the conditions of this field assay.

Our results indicate that symbiotic nitrogen fixation occurs in nodules of actinorhizal plants interplanted at this site with black walnut trees, and that the process is biochemically efficient. Nodular nitrogen fixation can occur during a 220-day period in actinorhizal plants in central Illinois, although the highest rates occur when soil temperatures approach 25°C during a 150-day period of peak activity during the growing season. Our finding that Russian olive plants lacked nodules on one site illustrates the importance of a systematic examination of the nodulation and nitrogen-fixation status of actinorhizal plants employed to improve N fertility in silvicultural systems.

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INOCULATION OF NORTHERN RED OAK SEEDLINGS WITH THE FUNGAL

SYMBIONT SUILLUS LUTEUS IN A MICHIGAN NURSERY[1]

Robert K. Dixon[2]

Abstract.--The ectomycorrhizal fungus Suillus luteus (L. ex Fr.) Peck, a symbiont adapted to prevailing environmental conditions in the northern U.S., is a promising candidate for routine nursery inoculation of seedlings. The purpose of this study was to introduce S. luteus into a Michigan nursery and evaluate the effect of inoculation on northern red oak (Q. rubra L.) seedling growth and ectomycorrhizal development. Suillus luteus inoculum was incorporated into fumigated nursery soil using two methods: banding or mixing. Placement of the inoculum influenced the number of seedlings colonized with S. luteus. Moreover, the spread of S. luteus mycelia was limited following banding of inoculum. Subsequent examination of seedling root systems revealed significantly different patterns of ectomycorrhizal colonization in the first year. After two years in the nursery seedling growth was significartly improved by inoculation with S. luteus.

## INTRODUCTION

The survival and early growth of container- and nursery-grown oak (Quercus) seedlings following outplanting on reforestation sties in the northern U.S. is generally unacceptable (Anderson, 1982). Early growth is characterized by periodic shoot dieback due to inadequate root-shoot ratios of seedlings (Johnson, 1984; Arend and Scholz, 1969). Frequently, nursery-grown oak planting stock lack mycorrhizal associations common to naturally occurring seedlings (Dixon et al, 1981a; Imshemetshii, 1967). The root-shoot balance and subsequent field growth of seedlings after outplanting can be improved following inoculation of the root system with compatible ectomycorrhizal fungi (Beckjord and McIntosh, 1984; Dixon et al, 1981b; Dixon et al, 1980).

Vegetative inocula of ectomycorrhizal fungi have been successfully introduced into conifer nurseries worldwide (Marx et al, 1984). However, previous reports reveal fungal symbionts and tree hosts often have specific ecological requirements (Perry et al, 1987). Thus, cultural practices in nurseries must be adjusted or developed to promote ectomycorrhizal symbiosis. The identification and evaluation of fungal symbionts compatable with red or white oaks have not been fully considered.

Members of the genus Quercus form ectomycorrhizal relationships with a number of fungal symbionts (Dixon et al, 1984). Ectomycorrhizal fungi in the genus Suillus are compatible with several oak species and stimulate early increases in seedling growth (Palm and Stewart, 1984; Dixon et al, 1984). Some species in the genus Suillus are not able to withstand the mechanical manipulation required during inoculum preparation (Dixon et al, 1984). However, ease of isolation, rapid growth in culture and the host specific tendency of some Suillus species may increase the utility of these fungi in nursery inoculation programs (Trappe, 1977).

The objectives of this study were to: 1) test feasibility of introducing Suillus luteus (L. ex Fr.) Peck into fumigated soil of a northern Michigan nursery, and 2) evaluate the effect of inoculum placement on the spread of fungal mycelia, ectomycorrhizal development and growth of northern red oak (Q. rubra L.) seedlings.

## MATERIALS AND METHODS

A single provenance of acorns was collected from the Huron-Manistee National Forest in west central Michigan. Acorns were sorted by flotation, graded to a standard weight and stratified (Dixon et al, 1984). Before planting acorns were surface sterilized with 10% sodium hypochlorite for 10 minutes. Suillus luteus was grown in a vermiculite-peat moss-nutrient mixture

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for three months to obtain vegetative inoculum using modified procedures described by Dixon et al (1984) and Marx and Bryan (1975).

The seedlings were grown at the USDA Forest Service J.W. Toumey Nursery, Watersmeet, Michigan. Nursery beds were tilled and fumigated under polyethylene with 400 kg/ha of methyl bromide (MC-33) before acorn sowing. Soil chemical properties of nursery soils were similar in all beds, pH 5.5 and 272 and 540 ppm of available $P_2O_5$ and $K_2O$, respectively. Dolomitic limestone was added to the beds to raise the exchangeable calcium and magnesium levels to approximately 1.0 milliequivalent per 100 g soil. The soil texture was a sandy loam, and organic matter was approximately 2% in all plots (Marx et al, 1984).

The study was implemented in a split-plot experimental design with 4 replications, 2 whole plots and 4 subplots. One whole plot was infested with vegetative inoculum of S. luteus, and the remaining whole plot was maintained as an uninoculated control. In the inoculated sub-plots, the vegetative inoculum was incorporated into the nursery soil using two methods: mixing or banding. Banded inoculum was manually placed approximately 10 centimeters under the acorns rows within the nursery bed. The mixed inoculum was broadcast over the nursery bed and tilled to a depth of approximately 20 centimeters. Inoculum density in both subplots was approximately 3 liters per $m^2$ of soil surface. The control plots received equal amounts of autoclaved inoculum using the same methods. Acorns were planted to obtain a density of 100 seedlings per $m^2$ in all plots.

The nursery beds were fertilized with three annual applications of ammonium sulfate ($(NH_4)_2SO_4$) (21-0-0 plus 24% sulphur). The granular fertilizer was applied at a rate of 9.2 kg/ha as a top dressing. The beds were irrigated with tap water as needed. Seedlings in all treatments were horizontally root pruned to a depth of approximately 23 cm in early August of each growing season.

A subsample of 25 randomly selected seedlings from each subplot replication was harvested in late June and September of the first growing season. Seedling root morphology, ectomycorrhizal development and the presence of fungal fruiting bodies in nursery beds were evaluated. In September of year two all nursery plots were undercut with a root pruning bar at a depth of 36 cm and seedlings lifted by hand. Fifty seedlings from each nursery sub-plot replication were randomly chosen for measurement of dry weight of roots and shoots (80°C, 48h), number of primary laterals, and number of S. luteus ectomycorrhizal laterals. Criteria for identifying ectomycorrhizal colonization are described by Dixon et al (1984). Reisolation of test fungi was attempted after seedling harvest using techniques described by Dixon et al (1984). Data was subjected to analysis of variance to determine effects of inoculum placement and inoculation on seedling growth and ectomycorrhizal development.

## RESULTS

Suillus luteus was successfully introduced into plots of northern red oak seedlings in the J.W. Toumey nursery (Table 1). Evaluation of seedlings on June 30 in the first growing season revealed the number of colonized plants and the percentage of ectomycorrhizal lateral roots colonized was greater in plots receiving mixed inoculum. Fruiting bodies of ectomycorrhizal

Table 1. Ectomycorrhizal development of northern red oak seedlings inoculated by two methods with Suillus luteus during the first growing season in J. W. Toumey nursery, Watersmeet, Michigan.

| Sampling date and seedling variable | inoculation treatment: mixed inoculum | banded inoculum | noninoculated |
|---|---|---|---|
| June 30 | | | |
| Seedlings colonized (%) | 47a[1] | 20b | 13b |
| Suillus laterals per seedling (%) | 36a | 19b | 0c |
| Total ectomycorrhizal laterals per seedling (%) | 21a | 24a | 10b |
| September 30 | | | |
| Seedlings colonized (%) | 93a | 80a | 73a |
| Suillus laterals per seedling (%) | 89a | 92a | 66a |
| Total ectomyccorrhizal laterals per seedling (%) | 74a | 68a | 39b |

[1]Means within a row sharing a common letter are not significantly different (P≤0.05).

fungi were not evident in late June.

Evaluation of northern red oak seedlings at the end of the first growing season (September 30) revealed significant ectomycorrhizal development by S. luteus in the inoculated plots. The percentage of seedlings successfully inoculated and the percentage of ectomycorrhizal lateral roots was greater than eighty percent. Seedlings in the control plots were partially colonized by indigenous fungi at the end of the first growing season. Fruiting bodies of Laccaria, Inocybe, Hebeloma, and Thelephora species were identified in the control plots.

At the end of two growing seasons in the Toumey nursery seedlings inoculated with S. luteus exhibited abundant ectomycorrhizal colonization (Table 2). Suillus luteus was reisolated from seedlings in each inoculated subplot. Seedling dry weight was significantly greater in plots inoculated with S. luteus. Within the control plots, ectomycorrhizal development by C. geophilum, L. laccata and T. terrestris was evident, but seedlings were 25% smaller than inoculated plants.

early development of ectomycorrhizae on northern red oak seedlings. Following soil fumigation, thorough mixing of inoculum into the seedling root zone will result in significant ectomycorrhizal colonization of primary lateral roots. Banding of the inoculum in the nursery bed is a useful operational technique for seedling inoculation. However, ectomycorrhizal colonization of seedlings of year one was less in treatments receiving banded inoculum. Inoculum mixing apparently increases the opportunity for lateral root contact with the vegetative mycelium.

Soil fumigation reduced ectomycorrhizal colonization of northern red oak seedlings in the control plots. Although indigenous ectomycorrhizal fungi eventually invaded the control plots significant quantities of ectomycorrhizae were not observed on seedlings until the end of the first growing season. Reduced ectomycorrhizal colonization resulted in significantly smaller seedling dry weights. Previous reports reveal a delay or lack of ectomycorrhizal colonization of oak will lead to nutritionally deficient and stunted seedlings (Mitchell et al, 1984; Dixon et al, 1981a).

Table 2. Total seedling dry weight and ectomycorrhizal development of 2-0 northern red oak seedlings inoculated by two methods with Suillus luteus after lifting (October) from J.W. Toumey nursery, Watersmeet, Michigan.

| Seedling variable | Inoculation treatment | | |
|---|---|---|---|
| | mixed inoculum | banded inoculum | noninoculated |
| Total seedling dry weight (g) | 16.9a[1] | 16.0a | 11.7b |
| Seedlings colonized (%) | 82a | 54b | 37c |
| Suillus laterals per seedling (%) | 78a | 77a | 5b |
| Total ectomycorrhizal laterals per seedling (%) | 85a | 89a | 46b |

[1]Means sharing a common letter are not significantly different ($P \leq 0.05$).

## DISCUSSION

Ectomycorrhizal inoculation of northern red oak seedlings with Suillus luteus in a northern Michigan nursery is feasible. The 110 day growing season, cool soil temperatures and cultural practices employed in the Toumey nursery did not impede ectomycorrhizal colonization of inoculated oak seedlings (Marx et al, 1984). Previously, inoculation of conifers with vegetative inoculum of Pisolithus tinctorius (Pers.) Coker and Couch in the Toumey nursery was relatively unsuccessful (Marx et al, 1984). These observations suggest the need for further testing of fungal isolates which survive prevailing environmental conditions in the northern U.S.

This study reveals vegetative inoculum of S. luteus can be a suitable form of inoculum for

Early seedling development of ectomycorrhizae by S. luteus resulted in significant increases in seedling total dry weight. Dixon et al (1984) observed a similar growth increase of container-grown white and black oak seedlings following inoculation with this isolate of S. luteus. In contrast, Dixon et al (1984) and Marx (1979) reported that isolates of S. cothurnatus Singer, S. pinorigidus Snell and Dick, S. hirtellus (Pk.) Kuntze and S. granulatus (L.:Fr.) Kuntz failed to form significant ectomycorrhizae with various oak hosts under a range of environmental conditions. These observations suggest oak seedling response to inoculation may be dependent on the Suillus isolate tested, inoculation techniques employed and the host x Suillus genotype combination (Palm and Stewart, 1984).

Growth and survival of oak seedlings following outplanting is the ultimate test of the benefits of ectomycorrhizal inoculation in the nursery (Parker et al, 1986). However, it is obvious from this study that early ectomycorrhizal development was associated with improvements in seedling size in the Toumey nursery. Inferences from previous reports suggest the large ectomycorrhizal oak seedlings with adequate root-shoot ratios will survive and compete with indigenous vegetation on routine and adverse reforestation sites (Dixon et al, 1981b). Oak seedlings with abundant S. luteus ectomycorrhizae from the Toumey nursery have been established in outplanting trials to ascertain benefits in the field.

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# IMPROVED MICROPROPAGATION OF WHITE ASH (FRAXINUS AMERICANA L.)[1]

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Abstract.--Cut, nonstratified seeds of white ash (Fraxinus americana L.) were surface-sterilized and germinated on four cytokinin-containing media. The best germination, explant growth, and axillary shoot proliferation occurred on Murashige and Skoog medium (MS) and on broadleaved tree medium (BTM). Cultures on woody plant medium (WPM) and Driver - Kuniyuki walnut medium (DKW) grew slowly. Because less callus formed from explants on MS medium, it was chosen over BTM for subsequent experiments. The best in vitro germination, explant stem growth, and axillary shoot proliferation were on MS medium supplemented with 3 µM thidiazuron (TDZ), 1 µM benzyladenine (BA), and 1 µM indole-3-butyric acid (IBA). Isopentenyladenine (2iP) was ineffective for initiating axillary shoot proliferation. Best rooting of axillary microshoots occurred using an 8 day dark pulse on MS supplemented with naphthalene acetic acid (NAA) and IBA both at 5 µM. Rooted microshoots were successfully acclimatized under mist in the greenhouse.

White ash (Fraxinus american L.) occurs widely throughout the central hardwood forests and is an important species for timber, landscaping, and wildlife (Fowells 1965). It is generally propagated from seeds (Bonner 1974); however, seedling variabililty is problem within this species because of natural heterozygosity and multiple ploidy levels (Clausen et al. 1981). White ash can be propagated vegetatively by means of cuttings, chip or T-budding, and whip and tongue grafting (Dirr 1977; MacDonald 1986). Compared to budding and grafting, micropropagation techniques could reduce costs and greatly increase the number of plants produced from selected clones.

Initial attempts to micropropagate white ash by Browne and Hicks (1983) resulted in some growth on dormant buds; however, long term growth and axillary shoot proliferation were not achieved. Recently, Preece et al. (1987) were successful in micropropagating white ash from seedling shoot tips. After 5 months on woody plant medium (WPM) supplemented with 5 or 10 mg liter$^{-1}$ benzyladenine (BA), axillary shoot proliferation averaged 3.5 shoot per culture. Axillary shoots could be rooted in WPM supplemented with indole-3-butyric acid (IBA) or in sterilized vermiculite without plant growth regulators. Subsequently, white ash was also micropropagated via somatic embryogenesis (Preece et al. 1989).

The choice of media and ratio of cytokinin to auxin can markedly affect axillary shoot proliferation and rooting. For black walnut, axillary shoot proliferation and elongation are much greater on Driver-Kuniyuki walnut (DKW) medium than on woody plant medium (WPM) (Hiele- Sudholt et al. 1986). Preece et al. (1989) found no differences in growth of white ash callus on four media supplemented with 2,4-D; however, similar studies have not been done to determine effects of media and cytokinins on axillary shoot proliferation. Although initial results by Preece et al. (1987) indicated white ash microshoots are easily rooted, the roots were often thickened and brittle suggesting additional refinements were needed.

The objectives of our experiments were to develop improved in vitro procedures for rapid production and rooting of white ash microshoots.

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## MATERIALS AND METHODS

Mature fruits were collected in 1987 from 10 widely-spaced trees throughout Jackson County, Illinois and stored dry in cloth bags at $4\pm2$ °C in darkness until used as explants. Samaras were detached and the apical one-fourth of each seed was removed. Cut seeds were sterilized in 1.05% sodium hypochlorite (NaClO or 20% Clorox) with 0.01% Tween-20 (polyoxyethylene sorbitan monolaurate) for 30 minutes. Seeds were rinsed three times in sterilized water and the apical end recut to reduce seeds to two-thirds the original size before placing on culture medium.

Stock solutions for woody plant medium (WPM) (Lloyd and McCown 1981), broad-leaved tree medium (BTM) (Chalupa 1984), Driver-Kuniyuki walnut medium (DKW) (Driver and Kuniyuki 1984), and Murashige and Skoog medium (MS) (Murashige and Skoog 1962) were prepared and stored at $4\pm1$ °C. All nutrient media was made up with 20 g $liter^{-1}$ sucrose and 1 µM indole-3-butyric acid (IBA). The cytokinins, thidiazuron (TDZ), benzyladenine (BA), and isopentenyladenine (2iP), were dissolved in a small amount of 1 N KOH. The auxins, IBA and naphthalene acetic acid (NAA), were dissolved in a small amount of ethanol before adding to nutrient media. The pH of each medium was adjusted to 5.8 with 1 N KOH or 1 N HCL before addition of 7 g $liter^{-1}$ Difco Bacto agar (when used). Media were distributed in 20 ml aliquots into 25 x 150 mm borosilicate glass culture tubes or in 30 ml aliquots to 120 ml glass jars (baby food) capped with clear autoclavable lids. Vessels and media were autoclaved for 20 minutes at 121 °C.

Explants were placed on agar-solidified medium and transferred monthly to new agar-solidified medium. Two weeks following each transfer, 10 ml of the same medium without agar was added aseptically to each culture. After one month in culture, the radicles were removed from germinated seed explants. The cotyledonary nodes were removed after two months in vitro. Cultures were incubated at $26\pm2$ °C with a 16 hour photoperiod and a PPF of 40 µM $m^{-2}$ $s^{-1}$ provided by cool white fluorescent lamps.

Explant epicotyl length, axillary shoot number and length, and callus volume ($2/3\ \pi r^2 h$) were determined at 2 week intervals. Number and length of roots were recorded at four day intervals in rooting studies. All experiments were arranged in a completely random design with a factorial combination of treatments. Data were subjected to analysis of variance.

## RESULTS AND DISCUSSION

### Axillary shoot proliferation studies

Explant germination percentage, stem length, number of axillary shoots after 12 weeks in culture were greater on BTM and MS medium than on WPM or DKW medium (Table 1). In addition, callus volume was greater on explants when grown on WPM and BTM than when grown on MS or DKW medium. Older parts of the callus mass frequently became brown which stained the culture medium and appeared to reduce shoot growth in these cultures. MS medium was used in all further experimemts because explants on MS showed good epicotyl elongation and shoot proliferation with minimal production of callus. Although not quantified, axillary shoots on MS medium usually had larger, greener leaves than on the other media. To reduce callus browning, 1 µM IBA was added to the medium.

Table 1.--Effects of media and BA after 12 weeks in vitro on explant germination, epicotyl length, axillary shoot number, and callus volume.

| Treatment | Germination | Epicotyl length | Axillary shoots | Callus volume |
|---|---|---|---|---|
| | (%) | (mm) | (no.) | ($mm^3$) |
| MEDIA | | | | |
| MS | 100 [a] | 33.3 [a] | 1.0 [a] | 78 [a] |
| BTM | 94 | 30.0 | 1.9 | 161 |
| WPM | 65 | 26.6 | 0.4 | 215 |
| DKW | 83 | 17.2 | 0.4 | 27 |
| 5% LSD= | | 6.1 | 0.7 | 80 |
| BA (µM) | | | | |
| 0.0 | 79 | 25.0 | 0.2 | 0 |
| 1.0 | 78 | 25.2 | 0.7 | 35 |
| 5.0 | 94 | 26.1 | 0.8 | 127 |
| 10.0 | 94 | 31.3 | 1.4 | 261 |
| 5% LSD= | | 6.1 | 0.7 | 81 |

a/ Each value represents the mean of 30 - 40 cultures.

Explant epicotyl length and axillary shoot production after 12 weeks in vitro were greater on medium supplemented with 10 µM BA than on medium supplemented with either 0.0, 1.0, or 5.0 µM BA (Table 1). Earlier work by Preece et al. (1987) using seedling shoot tips showed that consistent axillary shoot production on WPM was induced by 22 and 45 µM BA (5 and 10 mg $l^{-1}$, respectively). These BA levels, however, resulted in extensive callus formation on explants, especially if 4.9 µM IBA was added to the medium (Christ 1984). Preece et al (1989) showed that nonstratified seeds required transverse cutting to remove the apical end of each cotyledon before seeds would germinate. In our studies there was a trend for increasing amounts of BA to improve germination from cut unstratified seeds.

In experiments to test the effects of three cytokinins on axillary shoot proliferation, we found an interaction between TDZ, BA, and 2iP and their concentrations on axillary shoot production after 12 weeks in vitro (Figure 1). At 0.01 and 0.1 µM, TDZ, BA, or 2iP did not induce high axillary shoot proliferation rates. At 1 and 10 µM, TDZ was more effective than either BA or 2iP.

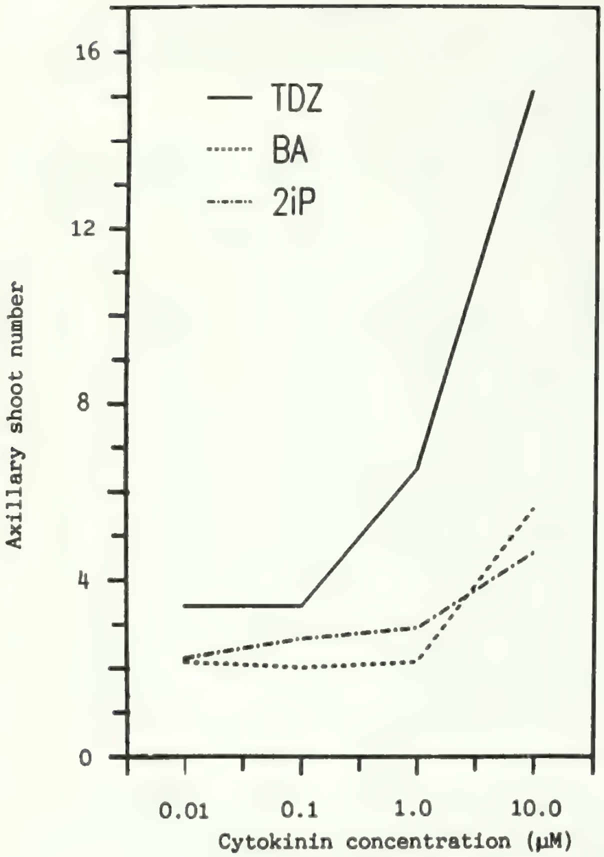


Figure 1.--Effect of cytokinins after 12 weeks on axillary shoot proliferation from cut seeds germinated in vitro.

The 15 axillary shoots per explant produced after 12 weeks in vitro with 10 µM TDZ is nearly 5 times the best rate previously reported for white ash (Preece et al 1987). Enhanced axillary shoot proliferation by TDZ has also been reported for apple and silver maple (Nieuwkerk et al. 1985; Ashby et al. 1987).

In other experiments to examine the type of explants to use for subculturing, we tested 2-node stem segments with and without leaves on factorial combination of 1, 3, and 10 µM of TDZ and BA. We found no differences in the number or length of axillary shoots between 3 and 10 µM TDZ; however, axillary shoots produced with 10 µM TDZ were abnormally thickened. The best axillary shoot proliferation with good elongation rates occurred when 1 µM BA and 3 µM TDZ were incorporated into MS medium. This experiment also showed that when leaves were retained on the 2-node stem segments, it increased the length of new axillary shoots.

Results from the above experiments suggest that our best axillary shoot proliferation and elongation with minimal callus formation was achieved by placing cut nonstratified seeds on agar-solidified MS medium supplemented with 3 µM TDZ, 1 µM BA, and 1 µM IBA. To maintain vigorous cultures, explants and subdivided axillary shoots need to be transferred monthly to new medium with the addition of liquid medium two weeks later.

## Rooting studies

Pulsing white ash microshoots for 8 days with 5 µM IBA in half-strength MS medium increased both the percentage of shoots rooting and the number of roots compared to pulsing without IBA (Table 2). The first adventitious roots were visible 10 to 14 days after initiating the auxin pulse. Shoots pulsed with 10 µM IBA showed more synchronous rooting than shoots pulsed without IBA. The later microshoots showed gradually increasing rooting percentages throughout a 42 day period. Whether the shoots were pulsed in the light or dark for 8 days with IBA had no effect on rooting; however, subsequent experiments showed that darkened pulses were slightly more effective than lighted pulses. The initiation of one or more roots inhibited the subsequent initiation of additional roots from the main stem. Overall rooting percentages in our experiments were lower than those reported by Preece et al. (1987); however, it was not necessary to add activated charcoal to the medium to prevent development of thickened, brittle roots observed with longer IBA pulses by Preece et al (1987).

Factorial combinations of NAA and IBA at 0, 1, and 5 µM as an 8 day darkened pulse were then tested. This was to determine what combination of auxins would stimulate rapid synchronous root initation on a high percentage of the shoots without producing thickened, brittle roots. There was an interaction between IBA and NAA for both the number of roots per microshoot and average root length 32 days after initiating treatments (Table 3). More microshoots were rooted when exposed to high auxin concentrations compared to low auxins concentrations after both 16 and 32 days. The combination of 5 µM NAA and 5 µM IBA

Table 2.--Rooting response of axillary microshoots in half-strength MS supplemented with IBA.

| IBA | Rooted shoots Day 20 | Rooted shoots Day 32 | Roots per shoot on day 32 | Average root length |
|---|---|---|---|---|
| (µM) | (%) | (%) | (no.) | (mm) |
| 0 | 3 [a] | 21 [a] | 0.8 [a] | 24 [b] |
| 1 | 27 | 41 | 1.0 | 27 |
| 5 | 27 | 64 | 1.1 | 28 |
| 10 | 17 | 31 | 0.9 | 24 |
| 5% LSD= | | | 0.2 | 11 |

a/Each value represents the mean of 27 to 33 microshoots.

b/For rooted microshoots on day 32 only.

Table 3.--Effects of NAA and IBA on rooting of microshoots in full-strength MS medium.

| Auxin level | | Rooted shoots | | Roots per shoot on day 32 | Average root length |
|---|---|---|---|---|---|
| NAA | IBA | Day 16 | Day 32 | | |
| (µM) | (µM) | (%) | (%) | (no.) | (mm) |
| 0 | 0 | 22 [a] | 78 [a] | 1.2 [a] | 23 [b] |
| 0 | 1 | 30 | 54 | 0.9 | 16 |
| 0 | 5 | 10 | 50 | 0.8 | 12 |
| 1 | 0 | 10 | 30 | 0.4 | 10 |
| 1 | 1 | 20 | 40 | 1.0 | 11 |
| 1 | 5 | 38 | 100 | 2.1 | 37 |
| 5 | 0 | 60 | 80 | 1.7 | 28 |
| 5 | 1 | 50 | 90 | 2.1 | 39 |
| 5 | 5 | 80 | 90 | 3.5 | 36 |
| 5% LSD= | | | | 0.9 | 15 |

a/Each value is the mean of 9 to 12 microshoots.

b/For rooted microshoots on day 32 only.

resulted in the greatest number of roots per shoot without formation of thickened, brittle roots. Rooting occurred more quickly on full-strength MS medium than on half-strength MS medium (data not presented) although the response to the auxin pulse was similar.

Rooted shoots were easily acclimatized to a greenhouse environment by transplanting to a sterilized commercial potting mixture and setting on a mist bench for approximately 4 weeks before moving to benches without mist. Initial growth consisted of simple leaves with a gradual transition to compound leaves by the third to fifth pair of new leaves.

## CONCLUSIONS

Best in vitro clonal propagation of white ash occurred on MS medium supplemented with 3 µM TDZ, 1 µM BA, and 1 µM IBA. To keep producing healthy axillary shoots, it is necessary to transfer them to new medium monthly. Our rooting studies indicate that rapid rooting of axillary shoots can be achieved in full-strength MS medium with 5 µM NAA and 5 µM IBA. This auxin combination induced rapid, synchronous rooting of normal appearing roots after 10 to 14 days. Rooted plantlets were easily acclimatized in the greenhouse by placing on mist benches for 4 weeks before transferring to benches without mist.

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# SURVIVAL AND DEVELOPMENT OF UNDERPLANTED NORTHERN RED OAK SEEDLINGS: 6-YEAR RESULTS[1]

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**ABSTRACT.**--A test was made of the performance of six types of northern red oak (Quercus rubra L.) nursery stock planted in the understory of a mature stand of upland hardwoods in southern Indiana. Manipulation of portions of the stand by thinning from below and chemical control of understory vegetation prior to underplanting resulted in four classes of stand condition in which seedling survival and growth were monitored. After 6 growing seasons, overall survival for all combinations of stand condition and seedling type was 50 percent and average seedling height was 60 centimeters (cm). Seedlings planted in areas receiving some type of cultural treatment achieved greater total heights, but survival was improved significantly only by the understory control treatment. Understory control alone had a greater positive effect on development of planted seedlings than did thinning alone. The combination of thinning from below to 60 percent stocking and understory control gave the best results in terms of seedling development, for all seedling types, as 56 percent of seedlings survived after 6 years with an average height of 78 cm. Nursery stock types differed little in their capacity to survive and develop. Mycorrhizae-inoculated seedlings displayed no increased survival or growth for either containerized or bare-root stock. Bare-root 1-0 stock grown in sub-irrigated nursery beds had higher survival and made comparable growth to larger 2-0 stock produced under identical nursery conditions. Containerized seedlings grew somewhat more rapidly than bare-root seedlings during the first 2 growing seasons following outplanting, but growth rates over the last 4 years were nearly the same for all six stock types, averaging about 5 cm per year. The greater costs and effort in producing, transporting, and planting oak seedlings grown in large containers are probably not justified by the small, short-term height growth advantage of containerization. Browsing by white-tailed deer throughout the 6-year study period has had a substantial impact. In the first growing season, 28 percent of all seedlings were browsed, with highest concentrations of deer activity in the brushy, unthinned/no understory control areas. As undergrowth has increased in the 6 years since treatment, so has browse incidence on planted oaks. Browse activity is now concentrated on the more vigorous seedlings growing in both thinned and understory control plots.

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## INTRODUCTION

Throughout the eastern hardwood region, the amount of naturally occurring advance oak reproduction in mature upland hardwood stands chronically fails to meet adequacy standards, particularly on good sites (Sander 1979, Mills et al 1987). As a part of the continuing effort to discover workable silvicultural techniques for reproducing oak stands, a study was initiated in 1982 in southern Indiana to assess the performance of various types of northern red oak nursery stock planted in an array of culturally manipulated understory conditions.

The rationale for enrichment plantings of desirable species in the understories of mature stands prior to harvest has been explored in some detail (Arend and Scholz 1969, Johnson 1980, Johnson 1984, Johnson et al 1986). A number of factors have been identified which contribute to difficulties in attaining satisfactory growth and survival of underplanted seedlings, most of which relate to root-shoot ratio imbalances in outplanted seedlings as well as unacceptably high levels of competition for light, nutrients, and water from adjacent vegetation (Johnson 1979, Wright et al 1985). This study was designed to test a variety of combinations of cultural stand treatments and nursery stock types in an attempt to identify the most successful techniques for artificially enhancing oak reproduction.

## METHODS

### Study Area

The investigation was conducted at the Southern Indiana Purdue Agricultural Center located in Dubois County, Indiana which is in the unglaciated Crawford Uplands Section of the Shawnee Hills Natural Region in south-central Indiana (Homoya et al 1985). Soils in the study area are predominantly of the Gilpin series (Ultic Hapludalfs) which have silt-loam textures, are well-drained and moderately permeable, contain abundant rock fragments, and are typically 42 inches in depth to siltstone bedrock. Slopes in the study area range in steepness from 6 to 20 percent and have a southern aspect.

Oaks comprised 75 percent of the sawtimber basal area of the stand prior to thinning. White oak (Quercus alba L.) was the most common species, followed by northern red oak (Q. rubra L.), black oak (Q. velutina L.) and scarlet oak (Q. coccinea L.). Hickories (Carya spp.), white ash (Fraxinus americana L.), and sugar maple (Acer saccharum Marsh.) made up the remaining one-fourth of sawtimber stocking. White oak site index was determined to be 70 feet (Carmean 1971).

In summer of 1982, one-half of the eight-acre study stand was thinned during the test of a mechanical system designed to harvest small, low quality trees that would normally be deadened as a part of timber stand improvement operations (Gibson et al 1983). Overall, thinned areas were reduced to an average 60 percent stocking level (Gingrich 1967). In early September, 1982, plots assigned the understory control treatment were mist-blown with a broadcast application of glyphosate (1.5 lb AE/acre) plus triclopyr (1.5 lb AE/acre) in 25 gallons water per acre. Follow-up tree injection with triclopyrl 1:1 was used to control understory vegetation greater than 3 meters (m) tall. One year following treatment, average control of understory vegetation was rated as 80 percent (Wright et al 1985).

### Study Design

Four two-acre plots were randomly assigned to two treatments (thinned, unthinned), with each of these whole unit plots repeated twice. Within each thinning treatment whole unit, four half-acre subunits were assigned randomly to two secondary cultural treatments (no understory control, understory control), each repeated twice, giving four half-acre understory control plots per thinning plot, a total of 16 subunits - 4 per whole unit. Sixteen seedlings of each of six types of nursery stock (total = 96) were planted in each of the half-acre treatment plots. Individuals from all stock type treatments were assigned totally at random within in the first subunit, with the 96-tree planting pattern repeated in the other 15 subunits. For analysis purposes, these assignments were treated as if they had been re-randomized in each subunit.

### Planting Stock

Six types of northern red oak nursery stock were planted on a 3 m x 3 m spacing in the center portion of each half-acre treatment plot. Sixteen seedlings of each stock type were planted for a total of 96 seedlings per treatment plot and 1536 seedlings in total for the entire area. Stock types included: 1) containerized 1-0 seedlings inoculated with the mycorrhizae-former, Pisolithus tinctorius (Pt), 2) containerized 1-0 non-inoculated stock, 3) bare-root 1-0 stock inoculated with Pt, 4) bare-root 1-0 non-inoculated stock, 5) bare-root 1-0 stock grown in sub-irrigated nursery beds, and 6) bare-root 2-0 stock grown in sub-irrigated nursery beds. In-depth descriptions of nursery procedures used in production of these six seedling types have been outlined by Wright et al (1985).

Seedlings were planted in Fall of 1982. Bare-root stock were planted using planting bars and spades, while containerized stock were

planted using standard-type post-hole diggers. Seedlings were graded by height during the planting process, with a cull-limit set at approximately 25 cm total seedling height to lend uniformity within stock types to the experiment. The 1-0 sub-irrigated stock ran smaller in height than other types, and cull-limit for these seedlings was set at 15 cm.

### Measurements

Seedling survival, height, and condition (browse, die-back, vigor) were checked after each of the first two growing seasons (1983 and 1984), and after the fourth (1986) and sixth (1988) growing seasons. Numbered metal tags on wire stakes at each seedling location were invaluable in allowing accurate seedling identification during the periodic measurements.

### Analysis

Six-year total height, combined 5th and 6th season height increment, and percent survival data were subjected to analysis of variance. Significant treatment mean differences were further separated with Duncan's New Multiple Range Test at P = 0.05.

## RESULTS AND DISCUSSION

### Survival

After six years, overall survival for all seedlings in all four stand condition classes was 50 percent. Survival differed substantially by stand condition, but to only a small extent with seedling type. Highest rates of survival were consistently associated with the understory control treatment, averaging 60 percent (64% - unthinned, 56% - thinned) with understory control and only 40 percent (48% - unthinned, 33% - thinned) without understory control (significant at $p < .01$) (table 1). For the four combinations of stand condition, survival ranged from a high of 64 percent for all seedling types planted in unthinned-understory control plots to a low of 33 percent in thinned plots with no understory weed control (table 1).

Regardless of stock type, it is clear that red oak seedlings did not survive well when under heavy competition from woody and herbaceous understory weeds. Thinning from below without controlling the understory by mist-blowing resulted in the highest rate of seedling mortality, probably because of the favorable conditions for rapid growth by both newly germinated and established undesirable species. Overall, seedlings in thinned plots had 44 percent survival compared to 56 percent survival in unthinned plots. Soil disturbance by mechanical thinning equipment likely increased the amount of understory regrowth, which would account for the conspicuously low rates of survival in thinned plots with no weed control. These areas, after six years, are note-worthy for their dense stands of undesirable competitors such as blackberry (Rubus spp.), poison-ivy (Toxicodendron radicans), greenbriar (Smilax spp.), and sassafras (Sassafras albidum).

Table 1.--Six-year survival and total height, and 5th and 6th year height increment by stand condition for underplanted northern red oak seedlings in southern Indiana.

| Stand Condition | Survival | Six-year height | Combined 5th & 6th year increment |
|---|---|---|---|
| | % | cm | cm |
| Unthinned, no understory control | 48 | 34 | 3 |
| Unthinned, understory control | 64 | 64 | 12 |
| Thinned, no understory control | 33 | 61 | 12 |
| Thinned, understory control | 56 | 78 | 18 |

Survival was extremely uniform among nursery stock types, with the exception of the bare-root 2-0 stock which had significantly lower ($p < .01$) survival than the other five types (table 2). Otherwise, there were no differences in survival attributable to seedling production methods or to interactions of seedling type with any of the combinations of cultural treatment. Bare-root stock survived as well as containerized stock, and non-inoculated stock survived as well as seedlings with nursery additions of Pt mycorrhizae. Confounding factors may be involved in stock-type performance comparisons and differences, above and beyond nursery production practices alone. These factors include differenes in planting techniques, variation in cull limits by seedling type, seed source variations, and the variable levels of naturally occurring mycorrhizae on non-inoculated seedlings.

The bare-root 2-0 seedlings had lowest survival rates, averaging only 36 percent, while the five other types survived about equally and averaged just over 50 percent for all combinations of stand condition. The lowered survival of the 2-0 stock is probably attributable to the difficulty of planting seedlings with extremely large and

well-developed lateral root systems, particularly in shallow, rocky soils. Conventional planting bars were not adequate to make suitable-sized holes to allow for proper placement of roots in the soil. A severe summer drought in 1983 may also have induced disproportionate mortality in the 2-0 stock, as second year survival for these seedlings was significantly lower than for the other five stock types (Wright et al 1985).

Survival was highest for bare-root 1-0 stock grown in sub-irrigated nursery beds and planted in unthinned plots with understory control (75 percent), and was lowest for bare-root 2-0 stock planted in thinned plots with no understory control (17 percent). High rates of survival (> 60 percent) were associated with all seedling types when competing understory vegetation was eliminated (table 2).

Total Height

The total height of surviving seedlings after six years was strongly influenced by thinning, understory control, and seedling type.

Table 2.--Six-year survival and total height, and 5th and 6th year height increment by seedling type for six nursery stock types of northern red oak underplanted in southern Indiana.

| Seedling type | Survival | Six-year height | Combined 5th & 6th year increment |
|---|---|---|---|
| | % | cm | cm |
| Containerized, Pt-inoculated | 51 a[1] | 68 a | 12 a |
| Containerized, not inoculated | 52 a | 64 ab | 9 a |
| Bare-root, Pt-inoculated | 56 a | 59 ab | 8 a |
| Bare-root, not inoculated | 50 a | 61 ab | 9 a |
| Bare-root, 1-0, sub-irrigated beds | 55 a | 48 c | 10 a |
| Bare-root, 20, sub-irrigated beds | 36 b | 56 bc | 19 a |

[1]Column values followed by the same letter are not significantly different (p <.05), based on Duncan's New Multiple Range Test.

Highly significant differences (p < .01) were detected for all of these main effects variables. However, no significant interactions existed for any of the combinations of treatments.

Northern red oak seedlings averaged 70 cm total height in thinned plots compared to just 49 cm in unthinned plots. Similarly, seedlings in plots receiving the understory control treatment had a mean total height of 71 cm versus (vs) only 48 cm for seedlings in plots with no understory control. Although fewer seedlings have survived in thinned - no understory control plots, those that remain have grown as well as seedlings in plots receiving the no thin - understory control treatment. Seedlings in unthinned areas with no understory control have achieved virtually no height growth in six years. These seedlings averaged just 34 cm total height, or less than half the size of seedlings in thinned, understory control plots which averaged 78 cm in height after six growing seasons (table 1).

Nursery stock type had a significant effect (p < .01) on six-year total height. However, the variable of total height in 1988 was found to be strongly correlated with original (1982) seedling height. Total height of each seedling at time of planting was not measured, thus analysis of covariance with original seedling height as the covariate was not possible. Since nursery production practices inherently influence size of seedlings, it was decided that height attainment comparisons between stock types are valid for the purposes of this study, keeping in mind that some differences between types may be relics of the original differences in size of planting stock.

Table 3 shows original mean seedling heights and six-year total heights (1988) for the six types of red oak planting stock. Duncan's mean separation procedure indicated no significant differences (p < .05) in six-year height between inoculated vs non-inoculated types or between containerized vs bare-root stock. Differences did exist between containerized-inoculated seedlings and the two types of sub-irrigated stock. Also, the 1-0 bare-root sub-irrigated stock were significantly smaller after six years than the four types of seedlings produced without sub-irrigation, a difference very probably linked to original seedling size. Examination of mean six-year height increment by seedling type indicates that growth rate potential of the initially smaller seedlings is not necessarily inferior to that of other types. Height development is important not only for chances for survival in the understory but for higher probabilities of successfully competing in the next stand. Therefore, planting large seedlings, up to a

practical limit, should result in larger size of artificial oak advance reproduction at the time of overstory removal.

### 5th - 6th Year Height Increment

Two-year periodic height increment (5th and 6th growing seasons combined) was determined for each seedling surviving in 1988 by computing the difference between 1988 and 1986 total height on a seedling by seedling basis. Comparisons using this rate make clear how well surviving seedlings are presently growing, and indicate to some extent whether or not treatment effects are still being expressed five to six years following study initiation.

Over the last two years, seedlings in thinned plots have grown at more than twice the rate (15 cm vs 7 cm) of seedlings in unthinned conditions. The same relationship and magnitude of difference holds for seedlings growing in areas with understory control vs no control. Seedlings in unthinned areas with no understory control grew 3 cm during this two-year interval, as compared with 18 cm height growth for oaks in thinned-understory control stand conditions (table 1). Without question, surviving seedlings continue to make acceptable growth only in areas that originally received some combination of thinning and/or understory control treatment. No significant differences between seedling types were detected by this analysis of recent growth rate trends (table 2).

Table 3.--Mean original seedling height, six-year height, and six-year height increment by seedling type for six northern red oak nursery stock types underplanted in southern Indiana.

| Seedling type | Mean height at planting | Mean six-year total height | Mean six-year height increment |
|---|---|---|---|
| | cm | | |
| Containerized, Pt-inoculated | 37 | 68 a[1] | 31 |
| Containerized, not inoculated | 34 | 64 ab | 30 |
| Bare-root, Pt-inoculated | 41 | 59 ab | 18 |
| Bare-root, not inoculated | 40 | 61 ab | 21 |
| Bare-root, 1-0, sub-irrigated beds | 20 | 48 c | 28 |
| Bare-root, 2-0, sub-irrigated beds | 32 | 56 bc | 24 |

[1]Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

### Deer Browse

At each measurement, incidence of browsing in the current year on the dominant shoot was tallied for each seedling. However, no quantitative measure of the effect of browsing on seedling height or survival was made. Therefore, only a qualitative discussion on the effects of browsing activity of white-tailed deer on seedling development is possible. Also, relative differences in browse activity and impact between treatments and measurement periods were compiled, and are presented here.

Browsing of oak seedlings was heaviest during the first year (1983) following planting. Of the 1,536 seedlings planted, 433 (28 percent) were browsed, with nearly half of this activity (47 percent) occurring in unthinned plots with no understory control. Not surprisingly, deer apparently spent more time in these thicker, brushy sections of the study area, and browse incidence on planted oaks showed this effect. Conversely, in this same year, seedlings planted in more open stand conditions (thinned with understory control) were browsed at the rate of only 14 percent.

After six years, the situation is quite different. Browse activity by deer is now concentrated on the more vigorous, palatable seedlings in areas that originally received understory control treatment. Also, browse incidence on surviving red oak seedlings in 1988 was only 12 percent (92/770). Increased amounts and diversity of desirable browse species, as well as greatly lowered numbers (density) of study seedlings, has lessened the pressure and effect of feeding deer on surviving underplanted red oaks.

The effects of browsing activity on the survival and development of planted seedlings are important to this discussion. In addition to improving growth and survival by reducing competition for light, water, and nutrients to underplanted oaks, the cultural treatments -- in particular, understory control -- also reduced incidence of deer browsing during the critical first year. It appears that had deer not been a factor in this study, there may not have been such dramatic differences in development between seedlings in treated and untreated areas.

## SUMMARY AND CONCLUSIONS

Underplanted northern red oak seedlings survived and developed best in conditions created by controlling competing understory vegetation. Growth was increased but survival was decreased by the addition of a thin-from-below treatment. Thinning or partial cutting to create shelterwood conditions causes soil disturbance and increased light levels at the forest floor, which in turn result in increased growth of competing vegetation. Without follow-up understory weed control, underplanted seedlings will perform relatively poorly under such conditions.

Seedling type in this experiment did not prove to be the key to success or failure. Survival was not linked to methods of nursery stock production, although plantability was shown to be important as survival was low for 2 year old seedlings with excessively large root systems, especially when planted under adverse conditions of shallow, rocky soils. Containerized seedlings had the highest initial growth rates, but survived no better and were not significantly larger after six years than bare-root seedlings. The small advantages of containerization do not warrant the extra production, transportation, and planting costs involved. Mycorrhizae-inoculated seedlings showed no superiority over non-inoculated seedlings. Of the six stock types used in this study, large 1-0 bare-root seedlings are the most desirable type of planting stock for use in oak underplanting when practical considerations are taken into account.

Potential impacts of deer browsing on the successful establishment of planted oaks should not be overlooked, even in areas with only moderately heavy deer densities (30-40/square mile). Browse impact on planted seedlings was reduced in this study by practices which controlled understory vegetation. Thick, brushy, stand conditions tended to attract deer, thus concentrating feeding activity on seedlings planted in these areas. Seedlings in the more open areas with understory control were much less affected by browsing activity. It is recommended that in areas with high deer populations, some consideration be given to protecting desirable regeneration from damage by browsing, particularly since establishment costs of artificial advance reproduction are high.

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EFFECTS OF SHADE AND HERBACEOUS VEGETATION ON FIRST-YEAR GERMINATION AND GROWTH OF DIRECT-SEEDED NORTHERN RED OAK, WHITE ASH, WHITE PINE, AND YELLOW-POPLAR[1]

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Abstract. First-year seed germination and seedling growth of northern red oak, white ash, white pine, and yellow-poplar were evaluated in 12 environments consisting of four levels of herbaceous interference (fern, fern-free, grass, grass-free) crossed with three levels of light intensity (100%, 45%, 20% full sun) at three clearcuts in central Pennsylvania. Germination differed among species, ranging from 84% for northern red oak to 2% for yellow-poplar. Germination differed significantly among sites or levels of herbaceous interference for all species except yellow-poplar. Grass and fern interference significantly reduced height or stem diameter of all species. Decreased light intensity reduced fern biomass at one site, and grass biomass at two sites. Decreased light intensity in the absence of fern and grass interference significantly reduced height and stem diameter of all species except white pine, while light had no significant effect on growth of any species in the presence of fern and grass interference. Tolerance to both fern and grass interference and shading was greatest for white pine, intermediate for northern red oak, and lowest for yellow-poplar and white ash.

Additional keywords: *Fraxinus americana* L., *Liriodendron tulipifera* L., *Quercus rubra* L., *Pinus strobus* L., competitive ability, shade tolerance, weed-induced stress.

INTRODUCTION

Interference from herbaceous plants is widely recognized as being detrimental to establishment of forest trees in old-field plantings. Herbaceous interference also can be a problem in natural regeneration by clearcut or shelterwood methods. This is especially true in Pennsylvania, where many clearcut sites are rapidly invaded by persistent herbaceous vegetation. While the effects of competing vegetation can be reduced by herbicide treatments, effects of other environmental factors on interference-induced stresses are poorly understood. Site dominance by inherently slow-growing forest trees may depend on at least moderate levels of environmental stress that enhance their competitive ability by reducing the growth of inherently faster-growing plants, such as many herbaceous species (Grime 1979). For example, northern red oak (*Quercus rubra* L.) in the Ohio Valley and Allegheny Plateau often occurs more frequently on xeric, south-facing slopes in contrast to mesic, north-facing slopes (Carvell and Tryon 1959, Carvell and Tryon 1961, Hicks and Frank 1984, McCarthy et al. 1984, Whitney 1982). This pattern of occurrence suggests that some degree of environmental stress favors its ecological success.

This study compares the effects of herbaceous interference on first-year seed germination and growth of northern red oak, white ash (*Fraxinus americana* L.), white pine (*Pinus strobus* L.), and yellow-poplar (*Liriodendron tulipifera* L.) under different levels of light intensity. Herbaceous interference can reduce seedling growth of all these species (Farmer 1981, Bowersox and McCormick 1987, Von Althen 1972), but white pine and northern red oak are typically more tolerant to interference than white ash and yellow-poplar (Bowersox and

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McCormick 1987). They also differ in tolerance to shading. Seedlings of white ash are typically considered to be shade tolerant, northern red oak and white pine are intermediate in tolerance, and yellow-poplar is shade intolerant (Daniel et al. 1979, Fowells 1965). The primary hypothesis is that given the presence of herbaceous interference, stresses induced by shading will increase the growth of these species compared to that in full sun. Also, we expect that more shade tolerant species, such as northern red oak or white ash, will respond to shading in the presence of herbaceous interference more favorably than a less shade tolerant species, such as yellow-poplar.

## METHODS AND MATERIALS

Seeds of northern red oak, white ash, white pine, and yellow-poplar were planted in spring 1987 into 12 environments consisting of four levels of herbaceous interference (grass, grass-free, fern, fern-free) crossed with three levels of light intensity (100%, 45%, 20% full sun). Each environment was replicated four times at each of three sites (four-hectares each) in the Ridge and Valley Province of central Pennsylvania (Harry's Valley, Laurel Run, Sandknob). All three sites were within 12km of each other on lower slopes in the same ridge system. All sites had similar topographic conditions except for aspect. Harry's Valley and Sandknob had a southeastern aspect and Laurel Run had a northwestern aspect. The sites received shelterwood cuts between 1970 and 1980 and were clearcut in 1984. Previous stands on all sites were dominated by oak species and the site index for northern red oak was about 70. All sites had unacceptably low numbers of advance regeneration of desirable tree species after harvest and were rapidly invaded by grass and fern communities. Numbers and composition of advanced regeneration and soil chemical properties for each site were described by Bowersox and McCormick (1987). Each site was enclosed by a five-strand electric fence to minimize deer browsing on seedlings.

In all environments, naturally occurring grass and fern communities covered from 80-100% of the soil surface at the onset of the study. Grass communities were primarily dominated by poverty oat grass (Danthonia spicata (L.) Beauv.), but also contained lesser proportions of Rubus L., goldenrod (Solidago L.), fireweed (Erechtides hieracitolia (L.) Rad.), whorled loosestrife (Lysimachia quadrifolia (L.) Ell.), hayscented fern (Dennstaedtia punctilobula L.), and sheep sorrell (Rumex acetosella L.). Fern communities were dominated by hayscented fern. Grass-free and fern-free environments were created by treating a 20m² portion of each community with glyphosphate (1.7 kg/ha) in late-April and mid-June 1987. Grass-free and fern-free environments were both free of all herbaceous vegetation and differed only in herbaceous composition prior to the study.

Grass and fern environments consisted of indigenous levels of herbaceous vegetation in each community. Woody stems were removed from all environments prior to the study.

At each level of herbaceous interference, treatments were applied using a split-plot design. Main plot levels of light intensity were randomly assigned to areas of 1m x 5m. Light levels of 45% and 20% full sun consisted of a canopy of black shade cloth which extended from the soil surface to a height of 1.2m. All sites were shaded from the first week of June to the end of October. Subplot levels of species were randomly assigned to planting spots at each light level. Seeds of all species were planted at Sandknob between April 15-16, Laurel Run between April 21-23, and Harry's Valley between May 1-5. Seed viability was evaluated by laboratory tests of germination over a 100-day period on samples of 300 seeds for each species.

Each species subplot consisted of a 1m² area containing six planting spots for white ash, white pine, and yellow-poplar, and nine planting spots for northern red oak. Each planting spot contained one pre-stratified seed for northern red oak, six seeds for white ash, five seeds for white pine, and 30 seeds for yellow-poplar, planted to a depth of 2cm. A total of 1296 seeds of northern red oak, 5184 seeds of white ash, 4320 seeds of white pine, and 25,920 seeds of yellow-poplar were planted over all sites. At each planting spot, seeds were protected from animal predation by a 10cm length of PVC tubing (2.5cm diameter for northern red oak and yellow-poplar, 1.3cm diameter for white ash and white pine) inserted into the soil to a depth of 5cm. The top opening of each seed protector was covered by a metal rod to prevent small mammals from removing seeds. In grass and fern environments, seed protectors were in direct contact with herbaceous vegetation. All planting spots were watered one week after planting to insure initial adequate soil moisture.

After the last week of June, all planting spots with multiple germinants were thinned to two seedlings to minimize competition between trees. Seedlings grew in the presence of seed protectors over the entire season with no apparent detrimental effects. In mid-August, herbaceous growth was measured at each light level in grass and fern environments. At each level of light, all herbaceous biomass in a randomly selected 0.25m² area was clipped, dried at 80°C for 24 hours, and weighed. Seedling height and stem diameter (1cm above the soil surface) were measured on the largest seedling in each planting spot in mid-October.

Cumulative germination percent, seedling height, stem diameter, and herbaceous biomass were analyzed by analysis of variance. Analyses of height, diameter, and germination were performed separately by species due to unequal error variances among species. All treatment effects were tested at the $p<0.05$ level. Mean

separations were performed using Fisher's protected least significant difference.

## RESULTS

### Germination

Germination percentages in laboratory tests were 70% for northern red oak, 85% for white pine, 6% for white ash, and 3% for yellow-poplar. In the field, end-of-season germination percentages averaged over all sites and environments were 84% for northern red oak, 48% for white pine, 20% for white ash, and 2% for yellow-poplar. Germination differed significantly among sites for all species except yellow-poplar. Average germination percentage for northern red oak and white ash was significantly greater at Laurel Run (90%, 31%, respectively) compared to Sandknob (82%, 13%, respectively) and Harry's Valley (81%, 15%, respectively). Average germination percentage for white pine was significantly greater at Sandknob (58%) and Laurel Run (52%) compared to Harry's Valley (32%). Germination differed significantly between levels of herbaceous interference at one site or more for northern red oak and white pine, but not white ash and yellow-poplar (Table 1). For northern red oak, germination percentages at all sites were significantly greater in the presence of grass and fern interference (mean of 88%) compared to interference-free environments (mean of 81%).

Table 1.--First-year percent germination[1] for northern red oak, white ash, white pine, and yellow-poplar with (Yes) and without (No) herbaceous interference at three sites, averaged over herbaceous communities and light levels. For each species, means in the same row followed by the same letter are not significantly different p<0.05.

| Site | Northern red oak | | White ash | | White pine | | Yellow-poplar | |
|---|---|---|---|---|---|---|---|---|
| | Yes | No | Yes | No | Yes | No | Yes | No |
| Laurel Run | 91a | 88b | 32a | 31a | 53a | 51a | 2a | 2a |
| Sandknob | 86a | 79b | 14a | 11a | 59a | 57a | 2a | 2a |
| Harry's Valley | 88a | 75b | 13a | 16a | 46a | 19b | 2a | 2a |

[1]Each value is the average of 216 seeds of northern red oak, 864 seeds of white ash, 720 seeds of white pine, and 4320 seeds of yellow-poplar.

For white pine, germination percentage at Harry's Valley was significantly greater in the presence of grass and fern interference (mean of 46%) compared to interference-free environments (mean of 19%), while interference had no significant effect at Laurel Run or Sandknob. Light intensity had no significant effect on germination of any species.

### Height growth

End-of-season seedling heights over all sites and environments averaged 18cm for northern red oak, 13cm for white ash, 8cm for yellow-poplar, and 7cm for white pine. Heights differed significantly among sites for all species, but differences were no more than 3cm for any species. At all sites, fern and grass interference at all levels of light intensity significantly reduced heights compared to interference-free environments for all species except white pine (Fig. 1). Effects of fern and grass interference were similar among sites for all species except yellow-poplar, where the average reduction in height at Sandknob (-54%) was greater than at Laurel Run (- 29%) or Harry's Valley (-26%). Averaged over all sites and light levels, herbaceous interference reduced the height of white ash by 65%, yellow-poplar by 60%, and northern red oak by 29% compared to interference-free environments. Northern red oak averaged 2.0 stem flushes in interference-free environments versus 1.2 flushes in grass and fern environments. Heights of all species did not differ significantly between fern and grass environments, or between grass-free and fern-free environments.

The effect of both fern and grass interference on northern red oak height was significantly greater in 100% sun than in shaded environments at both Harry's Valley and Sandknob, while effects of interference did not differ significantly among light levels at Laurel Run. Averaged over all sites, herbaceous interference reduced the height of northern red oak by 38% in 100% sun, 28% in 45% sun, and 20% in 20% sun. Effects of fern and grass interference did not differ significantly among light levels for other species.

Heights differed significantly among light levels in interference-free environments for all species except white pine, while light had no significant effect in grass and fern environments on any species (Fig. 1). In interference-free environments, average heights for northern red oak, white ash, and yellow-poplar were significantly greater in 100% sun compared to 45% and 20% sun. Decreasing light intensity from 100% to 20% sun in interference-free environments reduced the height of yellow-poplar by 40%, white ash by 31%, and northern red oak by 28%. Northern red oak in interference-free environments averaged 2.2 stem flushes in 100% sun, and 1.9 stem flushes in both 45% and 20% sun.

### Diameter growth

End-of-season stem diameter differed significantly among sites for all species except white pine. Average differences among sites were no more than 0.7mm for all species. At all sites,

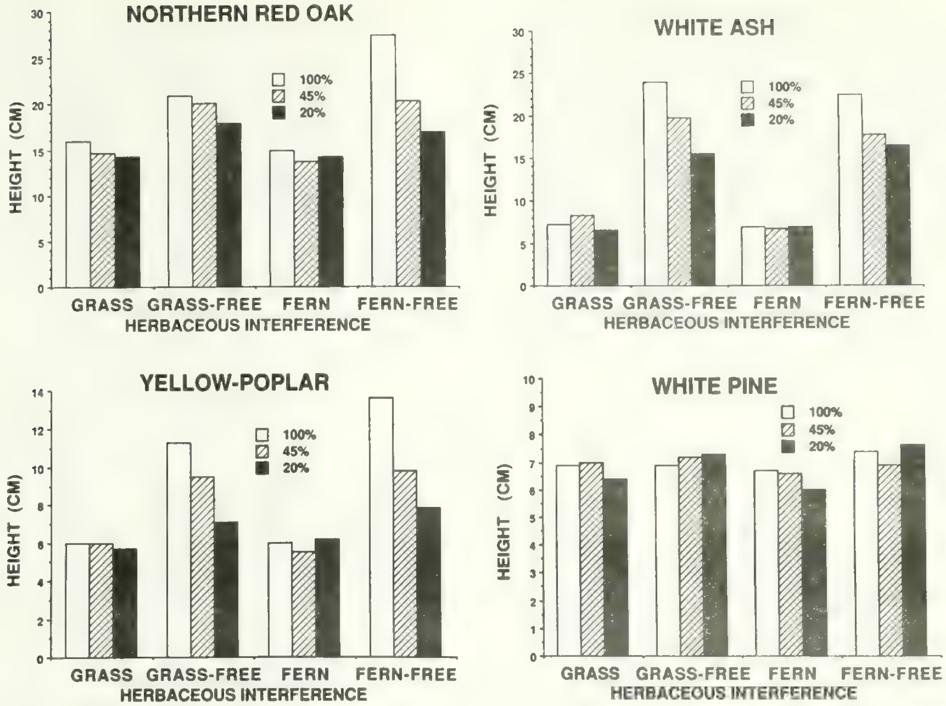


Figure 1.--First-year height of northern red oak, white pine, white ash, and yellow-poplar seedlings at four levels of herbaceous interference (grass, grass-free, fern, fern-free) and three levels of light intensity (100%, 45%, 20% sun). Each value is an average over three sites.

fern and grass interference at all light levels reduced stem diameter compared to interference-free environments for all species (Fig. 2).

For yellow-poplar, fern and grass interference reduced diameter more at Sandknob (mean of -64%) than at Harry's Valley (mean of -55%) or Laurel Run (mean of -54%). The effect of fern and grass interference did not differ significantly among sites for other species. Averaged over all sites and light levels, herbaceous interference reduced the diameter of white ash by 62%, yellow-poplar by 58%, northern red oak by 28%, and white pine by 23% compared to interference-free environments. Diameter did not differ significantly between grass and fern environments, or between grass-free and fern-free environments for any species except northern red oak, where average diameter in grass environments over all sites (3.1mm) was significantly greater than that in fern environments (2.8mm).

For northern red oak, the effect of fern and grass interference on diameter was significantly greater in 100% sun compared to shaded environments at Harry's Valley, while the effect of interference did not differ significantly among light levels at Laurel Run or Sandknob. Averaged over all sites, herbaceous interference reduced the diameter of northern red oak by 32% in 100% sun, 28% in 45% sun, and 24% in 20% sun compared to interference-free environments. Effects of fern and grass interference did not differ significantly among light levels for other species.

Diameter differed significantly among light levels for all species except white pine in interference-free environments, while light had no significant effect on any species in grass and fern environments (Fig. 2). In interference-free environments, average diameters for northern red oak and yellow-poplar were significantly greater in 100% and 45% sun compared to 20% sun, while average diameter for white ash was significantly greater in 100% sun compared to 20% sun. Decreasing light from 100% to 20% sun in interference-free environments reduced the diameter of yellow-poplar by 35%, white ash by 25%, and northern red oak by 20%.

Herbaceous growth

Oven dry herbaceous biomass in grass environments at Sandknob was significantly greater in 100% sun (230 g/m$^2$) compared to 45% (144 g/m$^2$) and 20% sun (125 g/m$^2$). Herbaceous biomass in grass environments at Harry's Valley was significantly greater in 100% (212 g/m$^2$) and 45% sun (198 g/m$^2$) compared to 20% sun (99 g/m$^2$). Light level had no significant effect on grass biomass at Laurel Run. Herbaceous biomass in

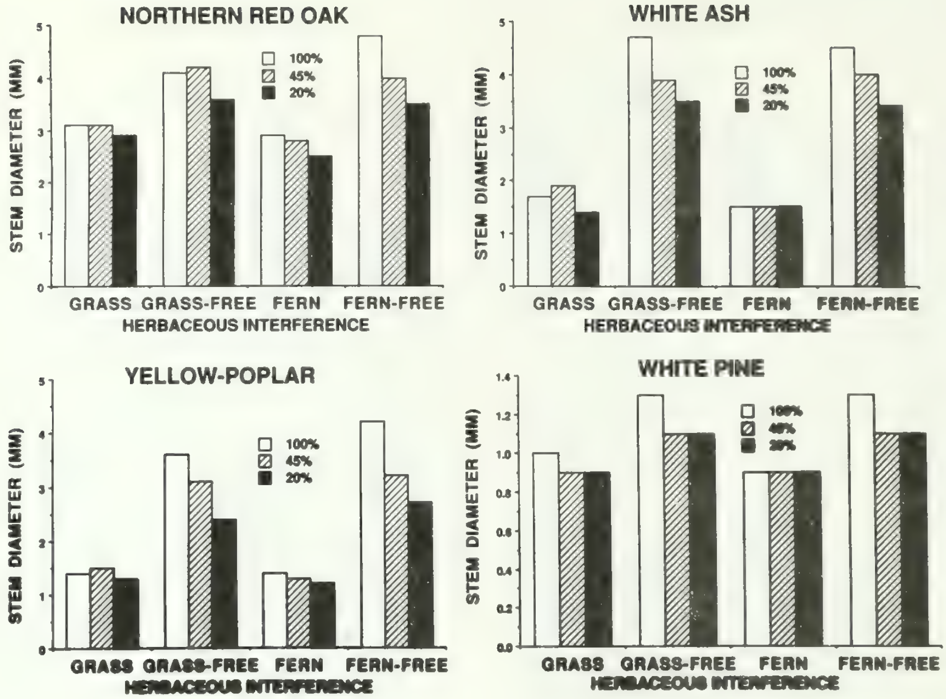


Figure 2.--First-year stem diameter (1 cm above ground level) of northern red oak, white pine, white ash, and yellow-poplar seedlings at four levels of herbaceous interference (grass, grass-free, fern, fern-free) and three levels of light intensity (100%, 45%, 20% sun). Each value is an average over three sites.

fern environments at Sandknob was significantly greater in 100% (270 g/m$^2$) and 45% sun (230 g/m$^2$) compared to 20% sun (140 g/m$^2$), while light intensity had no significant effect on fern biomass at Harry's Valley or Laurel Run.

## DISCUSSION

Germination percentages in the field for northern red oak, white pine, and yellow-poplar were similar to or greater than those in laboratory tests, while field germination for white pine was considerably lower than that in the laboratory. This suggests that the seed protectors, planting methods, or environmental conditions at the study sites may have reduced germination of white pine, but not the other species. Average field germination after one year at any site was at best 90% for northern red oak, 58% for white pine, 31% for white ash, and 2% for yellow-poplar. Low first-year field germination of white ash and yellow-poplar is common - seeds normally remain viable in the soil and germinate over a period of years (Marquis 1975). Germination percentages for northern red oak and white ash were higher on a northwestern aspect (Laurel Run) than on the two southeastern aspects (Sandknob and Harry's Valley), while aspect had no consistent effect on germination of white pine and yellow-poplar.

Northern red oak's consistently greater germination in grass and fern environments compared to interference-free environments can be attributed to either a beneficial influence of herbaceous cover, or a detrimental effect of the glyphosphate herbicide used to control herbaceous growth. Glyphosphate has been reported to have no effect on northern red oak germination in forest soils (Shipman and Prunty 1988), suggesting that herbaceous cover aided germination, perhaps by moderating soil moisture.

Differences in first-year height growth among these species were directly related to initial seed size. Average height of northern red oak, the largest seeded species, was more than twice that of white pine and yellow-poplar, the two smallest seeded species. Species ranking in increasing susceptibility of first-year growth to herbaceous interference was: white pine, northern red oak, yellow-poplar, and white ash. This ranking of susceptibility to herbaceous interference is similar to that reported by Bowersox and McCormick (1987) for two-year growth of bareroot seedlings of these species planted on the same three sites. Species ranking in increasing susceptibility of first-year growth to shading (white pine, northern red oak, white ash, yellow-poplar) was similar to that for susceptibility to herbaceous interference. Thus, first-year tolerance to both herbaceous

interference and shading was greatest for white pine, intermediate for northern red oak, and lowest for yellow-poplar and white ash. Our ranking in shade tolerance for these species is fairly consistent with previous assessments (Daniel et al. 1979, Fowells 1965), except for placement of white ash. White ash is typically considered to be tolerant of shade as a seedling (Fowells 1965). For example, Logan (1973) reported greater growth of white ash seedlings in 45% compared to 100% sun. In contrast, growth of white ash seedlings in our study was greater in 100% compared to 45% sun.

Total above-ground growth of tree seedlings plus herbaceous plants was generally lower in shaded compared to full-sun environments. Shading reduced herbaceous growth at two sites, but had no effect on growth of any tree species in the presence of interference. This suggests a redistribution of total biomass from herbaceous plants to tree seedlings in response to shading. Despite the apparent more favorable competitive position of these tree seedlings in shade compared to full sun, seedlings of all species were still severely suppressed by herbaceous interference. Thus, the slight competitive advantage over herbaceous vegetation provided these tree seedlings by shading had little practical significance in the first growing season, although stronger differences may arise in later years.

## CONCLUSIONS

1) Fern and grass interference had a slight beneficial influence on germination of northern red oak and, to a lesser extent, white pine, but not white ash and yellow-poplar.

2) Fern and grass interference reduced first-year growth of all species. Species' ranking in order of increasing susceptibility to interference was: white pine, northern red oak, yellow-poplar, white ash.

3) First-year growth of northern red oak, white ash, and yellow-poplar was reduced by levels of light intensity below one half full sun, while growth of white pine was unaffected by light levels as low as 20% full sun. Species' ranking in order of increasing susceptibility to shading was: white pine, northern red oak, white ash, and yellow-poplar.

4) Given the presence of fern and grass interference, levels of light intensity between 100% and 20% full sun had no effect on first-year growth of northern red oak, white ash, white pine, and yellow-poplar.

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RELATING BLACK WALNUT PLANTING STOCK QUALITY TO FIELD PERFORMANCE[1]

W. J. Rietveld and J. W. Van Sambeek[2]

Abstract.--Planting stock quality and field performance of seedlings stored totally enclosed in poly-lined Kraft bags or roots only enclosed with or without moist peat were similar to those of spring-lifted seedlings. Seedlings heeled-in overwinter or cold-stored without packaging were of lesser quality. Correlations of 27 measured variables of planting stock at planting time with 10 measured field response variables revealed 13 variables strongly related to initial survival and growth.

## INTRODUCTION

"Transplant stress," i.e., retarded initial growth following outplanting, is a persistent problem with several hardwood species. Survival and subsequent shoot growth of outplanted seedlings depend on the rapid establishment of a vigorous root system (Rietveld 1989). Transplant stress has led to several investigations of planting stock quality and its relation to initial root development and subsequent seedling establishment.

Packaging and overwinter storage can markedly affect physiological quality of planting stock (Webb and von Althen 1980; von Althen and Webb 1981, 1982). Our research with packaging methods and overwinter storage of black walnut (Juglans nigra L.) planting stock reaffirms earlier work by Webb and von Althen, and identifies several potentially useful relationships between planting stock characteristics at time of planting and field performance.

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[2]Supervisory Plant Physiologists, Rocky Mountain Forest and Range Experiment Station, Lincoln, Nebr., and North Central Experiment Station, Carbondale, Ill., respectively. We wish to thank Dr. Jim Wichman, nurseryman at the Vallonia Forest Nursery, Brownstown, Ind., for his cooperation, Mr. David J. Polak, computer programmer, for data analysis; and the Shawnee National Forest for the planting site.

## METHODS

Black walnut (1-0) seedlings were grown at the Vallonia Forest Nursery, Ind.,(Lat. N38° 47', Long. W 86° 05'). Seedlings were randomly lifted by hand from beds of regular nursery stock on December 3, 1980, root pruned to 20 cm, randomly assigned to packaging treatments, and immediately packaged for overwinter cold storage. The packaging methods tested were: 1) roots packed in moist peat, seedlings totally enclosed in poly-lined Kraft bags; 2) roots packed in moist peat, roots enclosed in poly-lined Kraft bags tied just above the root collar; 3) no peat around roots, seedling roots enclosed in poly-lined Kraft bags tied just above the root collar; and 4) no packaging, seedlings stored bare-root. In addition, for comparative purposes: 5) one group of seedlings was heeled-in overwinter at the nursery by placing them vertically in a trench and backfilling with soil; and 6) one group of seedlings was lifted on March 3, 1981, from the same nursery beds and temporarily packaged the same as treatment 1 to serve as a spring-lifted control. Cold storage temperature was 1° C and relative humidity was kept as high as possible by frequent wetting of the floor.

In April 1981, random samples of stock from each treatment were taken for the following measurements: 1) 25 seedlings for measurement of shoot and root xylem water potential (XWP), 2) 4 seedlings for estimation of root starch concentration, 3) 24 seedlings for determination of root growth potential (RGP), and 4) 50 seedlings for a field test.

Xylem water potential (XWP) to a minimum of -3500 kPa was determined on the terminal 12.5 cm (5 in) of the shoot and one large

lateral root of each seedling, using the pressure chamber technique of Scholander et al. (1965). Root starch concentration was estimated using the sectioning, staining, and visual estimation technique of Wargo (1975).

Root growth potential (RGP) was measured using the method reported by Rietveld and Williams 1981. Eight seedlings were planted in 20-l plastic pots filled with washed river sand and set in a greenhouse (temperature >18° C <30° C) under an extended photoperiod of 16 hours. Individual seedlings were examined twice weekly for bud burst. After 32 days the seedlings were removed from the pots by gently washing the sand from the roots. Seedling shoots were immediately measured for amount of die-back on the previous year's growth (shoot tip die-back), number and total length of new shoots, and number and total length of new leaves. Seedling root systems were measured for total number, area, and length of all new roots more than 1 cm long. Area was determined with a LI-COR[1/] area meter. The root system was separated into new roots, lateral roots, and taproot to determine dry weight of each. Percent of taproot discoloration or decay was visually estimated by cutting the taproot into thirds and examining the apical end of each section.

The field study, on the Shawnee National Forest in southern Illinois, was located on a deep, well-drained Ava silt loam suitable for good walnut growth. The test consisted of five randomized complete blocks containing 10 seedlings per treatment per block. Seedlings were hand planted with a planting bar at 1 m x 1.5 m spacing on April 14, 1981. Competing vegetation was effectively controlled with one application of glyphosate (3.08 kg a.i./ha = 2.75 lb/A) plus simazine (4.8 kg a.i./ha = 4 lb/A) at time of planting. Seedlings were examined twice weekly for bud burst. Total height and stem diameter 3 cm above soil line was measured at planting and at the end of the first and second growing seasons. Additional fall measurements included length of the longest new shoot (terminal shoot growth) and total length of all lateral shoots (lateral shoot growth).

All data were analyzed for significant differences by ANOVA and Duncan's new multiple range test (a = 0.05) using treatment means for individual seedling data for XWP and starch concentration, pot means for RGP, and block means for the field study. Correlation coefficients were based on six pairs of sample means; absolute r-values of 0.754 and 0.874 at $P \leq 0.05$ and 0.01, respectively, were required for significance.

[1]Trade names are included for the information of the reader and do not constitute endorsement by the USDA Forest Service.

## RESULTS AND DISCUSSION

### Growth Responses in Root Growth Potential Test

Seedlings from the various packaging and overwintering treatments showed variable flushing of terminal buds (table 1). Only eight seedlings in the cold-stored bare-root treatment burst buds during the 32-day greenhouse test, and most died back to the root collar and resprouted. Heeled-in and spring-lifted seedlings that overwintered in the nursery burst buds 4 to 10 days sooner than packaged and cold-stored seedlings. Seedlings that overwintered outside had slightly more shoot tip die-back than the packaged, cold-stored seedlings, but the differences were not significant.

Shoot growth responses of the three packaged, cold-stored treatments and spring-lifted seedlings were very similar. Responses of seedlings totally enclosed in poly-lined Kraft bags were slightly better than those of seedlings packaged with roots only enclosed or spring-lifted. Packing roots in moist peat moss had little effect. Heeled-in seedlings were generally retarded. The earlier flushing date of spring-lifted and heeled-in seedlings did not result in more growth during the 32-day test period.

We observed no significant effects of packaging and overwintering treatments on RGP responses because of the high variability of root growth responses among individual seedlings and among pots. Dry weight of new roots ranged from 0 to 214.6 mg for the packaged and cold-stored seedlings. None of the seedlings cold-stored with exposed roots had any new root growth, and only two-thirds of the heeled-in seedlings had any new root growth. Although other authors (e.g., von Althen and Webb 1978) have reported that early shoot extension of hardwood planting stock is strongly correlated with the plant's ability to produce new roots, we found that root growth (dry weight) was only weakly related to new shoot growth (dry weight) ($r^2 = 0.2678$, $F = 38.4$; df = 1,105). This analysis excluded the seedlings cold stored with exposed roots.

The numerical data in table 1 suggest that totally enclosing seedlings in poly-lined Kraft bags resulted in a slightly better RGP response than packaging roots only, with or without moist peat moss, or spring-lifting. Statistically, the four treatments are similar.

### Seedling Characteristics at Planting Time

Shoot and root dry weight and shoot:root dry weight ratio of seedlings in the RGP study differed significantly among the six packaging and overwintering treatments after 32 days in the greenhouse (table 2). Most of the effect

Table 1.--Growth responses in root growth potential (RGP) tests of black walnut planting stock subjected to different packaging and overwintering treatments. Data are means of 24 seedlings.

| | Packaging Treatment | | | | | |
|---|---|---|---|---|---|---|
| Growth response variable[1] | Spring lifted | Seedling enclosed in bag | Roots in bag with moss | Roots in bag no moss | Heeled in | Bare-root |
| Seedlings bursting bud (%) | 100.0a[2] | 100.0a | 100.0a | 100.0a | 79.0b | 33.0c |
| Time to bud burst (days) | 11.1b | 15.4a | 19.2a | 15.4a | 9.1b | 29.3[3] |
| Terminal shoot dieback (cm) | 1.7 | 0.1 | 0.0 | 0.0 | 1.6 | 29.4 |
| Number of new shoots | 1.8a | 1.7a | 1.5ab | 1.4b | 1.3b | 0.4c |
| Total length new shoots (cm) | 6.1ab | 6.8a | 4.1bc | 4.1bc | 3.3c | 0.9d |
| Number of new leaves | 7.3a | 8.1a | 6.6a | 7.0a | 4.7b | 0.6c |
| Total length new leaves (cm) | 71.7abc | 94.4a | 60.6bc | 82.0ab | 42.5c | 0.4d |
| Dry weight new shoots & leaves (g) | 1.344a | 1.416a | 0.984a | 1.370a | 0.712a | 0.017b |
| Number of new roots[4] | 35.3 | 36.0 | 24.6 | 23.1 | 17.7 | 0.0 |
| Total length new roots (cm) | 98.1 | 98.7 | 70.3 | 59.1 | 44.6 | 0.0 |
| Total area new roots ($cm^2$) | 5.21 | 4.99 | 3.71 | 3.68 | 2.40 | 0.0 |
| Dry weight new roots (g) | 0.037 | 0.037 | 0.029 | 0.023 | 0.011 | 0.000 |
| Average new shoot length (cm) | 3.5a | 4.0a | 3.1ab | 3.0ab | 1.9b | 0.7c |
| Average new leaf length (cm) | 10.0a | 11.8a | 9.1ab | 11.8a | 6.5b | 0.2c |
| Average new root length (cm) | 2.8 | 2.5 | 2.8 | 2.4 | 2.5 | 0.0 |
| Average new root area (cm) | 0.17 | 0.13 | 0.14 | 0.15 | 0.11 | 0.0 |
| Decay in upper taproot (%) | 5.0c | 2.5c | 0.8c | 0.4c | 27.1b | 48.3a |
| Decay in middle taproot (%) | 7.1c | 3.3c | 2.5c | 2.9c | 27.0b | 76.2a |

[1] Dead seedlings were not excluded and were assigned a value of zero for most variables.
[2] Numbers in each row followed by the same letter are not significantly different at the 5% level. Treatments not followed by a letter showed no significant differences.
[3] Only eight seedlings burst buds; the remaining seedlings were assigned a value of 32 days, the length of the test.
[4] Root data are for first order roots ≥ 1.0 cm in length.

was due to differences among root dry weights. We did not weigh the seedlings before potting, so we did not know if the differences at planting time resulted from initial differences in seedling weight, from overwinter depletion, or from depletion during the RGP tests. Because all seedlings were lifted at the same time and randomly assigned to treatments (except spring-lifted seedlings), and height and caliper at the time of potting were similar (table 2), we assume their initial weights were similar. The root starch concentration data from dormant seedlings (table 2) do not clearly support any of the alternative causes for the differences.

In another study, black walnut seedlings from the same population were carefully excavated from the nursery beds to retain as much of the root system as possible. One-half of the seedlings were root pruned similar to the seedlings in this study. Shoot:root ratio of the unpruned seedlings averaged 0.238 compared to 0.303 for the pruned seedlings. These results would indicate that shoot-root ratios at the end of RGP tests (including new root and shoot growth) approximate the shoot:root ratio of stored seedlings at time of planting, and that some materials were apparently translocated to the shoots during the RGP tests. As expected, shoot xylem water potential was lowest in seedlings cold-stored with roots exposed (table 2). Root xylem water potential was more difficult to measure and more variable. Xylem water potential was generally low in seedlings from all the packaging and/or overwintering treatments. Only the least favorable treatments (cold-stored bare-root and heeled-in) were statistically distinguishable from the other treatments. There were no significant differences among treatments that enclosed the total seedling or root portion of the seedling with or without peat moss.

## Field Growth Responses

At planting, soil moisture was marginal; precipitation during the previous 12 months was 47 cm below the normal of 116 cm. Significant rainfall did not occur for another 4 days, then was 27 cm above the normal 45 cm expected for the remainder of the growing season.

Table 2.--Physical and physiological characteristics of black walnut planting stock at time of planting for 6 packaging and overwintering treatments. Dry weight data are means of 24 seedlings, xylem water potential data are means of 25 seedlings, and starch concentration data are means of 4 seedlings.

| Seedling characteristic | Packaging Treatment: Spring lifted | Seedling enclosed in bag | Roots in bag with moss | Roots in bag no moss | Heeled in | Bare-root |
|---|---|---|---|---|---|---|
| Shoot length (cm) | 36.9c | 41.0b | 34.4bc | 46.6a | 35.2c | 49.2a |
| Shoot basal diameter (mm) | 8.9a | 9.3a | 8.8a | 9.2a | 8.8a | 8.2a |
| Height/diameter ratio (cm/mm) | 4.18c | 4.46bc | 4.49bc | 5.14b | 4.06c | 6.07a |
| Shoot dry weight[1] (g) | 5.835c | 7.536abc | 6.134c | 8.401a | 5.932bc | 6.439ab |
| Root dry weight[1] (g) | 10.373d | 17.374a | 13.388bc | 16.026ab | 11.867cd | 10.761cd |
| Total dry weight[1] (g) | 16.208b | 24.910a | 19.522b | 24.427a | 17.799b | 17.200b |
| Shoot/root ratio[1] | 0.56c | 0.43a | 0.46ab | 0.52bc | 0.50abc | 0.60c |
| Shoot xylem water potential (-kPa) | 16.46b | 14.30a | 15.95b | 10.93a | 14.72b | 31.40c |
| Root xylem water potential (-kPa) | 10.83a | 19.51bcd | 13.86ab | 15.61abc | 21.94cd | 25.78d |
| Root starch concentration (%) | 18.8b | 32.5a | 31.2a | 30.0a | 17.5a | 20.0b |

[1]From RGP tests, includes new growth.

As in the RGP test, spring-lifted and heeled-in seedlings that overwintered outside burst buds 3-8 days sooner than cold-stored seedlings, but the differences had no effect on net growth at the end of the growing season (table 3). Most of the unpackaged cold-stored seedlings that survived died back to the ground and sprouted from the root collar, resulting in a decrement in height and diameter growth at the end of the season.

Survival, height growth, and diameter growth data support the same ranking of treatments as in the RGP test. That is, seedlings packaged totally enclosed in poly-lined Kraft bags performed slightly better numerically, but the difference was statistically indistinguishable from the seedlings with roots only enclosed and from the spring-lifted seedlings. The heeled-in seedlings had lower survival and grew less the first year, but performed almost as well as the other treatments during the second growing season. The cold-stored bare-ro t seedlings had low survival and growth the first year. Survival continued to decline the second year, but seedlings that did survive grew well.

Table 3.--Field growth responses of black walnut planting stock subjected to different packaging and overwintering treatments. Data are the means of 50 seedlings.

| Growing season after planting | Growth response variable[1] | Packaging Treatment: Spring lifted | Seedling enclosed in bag | Roots in bag with moss | Roots in bag no moss | Heeled in | Bare-root |
|---|---|---|---|---|---|---|---|
| 1 | Time to bud burst (days) | 17.9cd[2] | 21.0bc | 22.8b | 22.7b | 16.4b | 44.4a |
| 1 | Terminal shoot die-back (cm) | 3.6b | 2.1b | 2.8b | 2.2b | 4.9b | 20.6a |
| 1 | Survival (%) | 98.0a | 100.0a | 100.0a | 100.0a | 86.0b | 50.0c |
| 2 | Survival (%) | 98.0a | 100.0a | 100.0a | 100.0a | 82.0b | 26.0c |
| 1 | Terminal shoot growth (cm) | 18.1ab | 21.4a | 16.1ab | 19.6ab | 18.0ab | 13.0b |
| 1 | Lateral shoot growth (cm) | 5.6ab | 9.3a | 8.0a | 6.9ab | 3.7bc | 1.1c |
| 1 | Net height growth (cm) | 14.6ab | 20.0a | 14.1ab | 18.0ab | 12.5b | -30.5c |
| 1 | Net diameter growth (cm) | 7.0ab | 7.9a | 7.0ab | 7.9a | 6.1b | - 2.3c |
| 2 | Net height growth (cm) | 99.1a | 100.8a | 102.5a | 104.5a | 110.8a | 76.5b |
| 2 | Net diameter growth (cm) | 17.4a | 17.8a | 17.9a | 18.7a | 18.4a | 12.1b |

[1]Means exclude all dead seedlings found at the end of each growing season.
[2]Means followed by the same letter are not significantly different according to Duncan's new multiple range test.

## Relation Between Planting Stock Characteristics at Planting Time and Field Performance

Because the packaging and overwintering treatments produced planting stock of variable quality, this study allowed us to correlate numerous planting stock characteristics determined at planting time with several field growth response variables. We therefore ran simple correlations of shoot and root growth responses in RGP tests (table 1) and seedling characteristics (table 2) with field growth responses (table 3). The resultant correlations (table 4) indicate that the seedling characteristics that are highly correlated ($P \leq 0.01$) with field survival and growth are: shoot tip die-back, average new shoot length, number of new leaves, total length of new leaves, average new leaf length, dry weight of new shoots and leaves, number of new roots, average new root length, total area of new roots, average new root area, occurrence of taproot discoloration and decay, shoot basal diameter, and shoot xylem water potential. The average lengths for new shoot, new leaf, new root and average area of new roots in RGP tests were surprisingly well correlated with field survival and growth. Discoloration and decay in cross sections of the upper and middle taproot at the end of the RGP tests were also surprisingly well correlated with field survival and growth. Heeled-in seedlings had 27 percent decay at both taproot cross-sections; seedlings stored bare-root had 48 and 76 percent decay in upper and lower taproot cross sections, respectively (table 1). The remaining treatments had 0.4 to 7.1 percent decay or discoloration. Time to bud burst and shoot tip die-back seem to be good early indicators of planting stock quality, both in RGP tests and in the field.

Shoot basal diameter (3 cm above root collar) was the only seedling morphological characteristic of planting stock that was strongly correlated with field growth responses (survival and diameter growth, but not height growth). This relationship is consistent with our previous finding that basal diameter increment is strongly related to first-year root growth in dry weight (van Sambeek and Rietveld 1983). Height:diameter ratio of planting stock was also a reasonably good indicator of field performance.

Shoot xylem water potential was found to be highly correlated with field survival and is much easier to measure than RGP. Webb and von

Table 4.--Simple correlations of shoot and root growth responses in root growth potential (RGP) tests and seedling characteristics at time of planting, versus field growth responses. Correlation coefficients are based on six pairs of sample means representing the packaging/overwintering treatments. For significance at $P \leq 0.05$ and 0.01, r values of 0.754 and 0.847, respectively, are required.

| Variable X | Variable Y / Field growth response: Time to bud burst (days) | Terminal shoot dieback (cm) | First-year survival (%) | Second-year survival (%) | Terminal shoot growth (cm) | Lateral shoot growth (cm) | Net 1st yr height growth (cm) | Net 1st yr diameter growth (mm) | Net 2nd yr height growth (cm) | Net 2nd yr diameter growth (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| A. Shoot response in RGP test | | | | | | | | | | |
| Time to bud burst (days) | .96**[1] | .80* | -.73 | -.75* | -.72 | -.40 | -.83* | -.81* | -.89** | -.85* |
| Terminal shoot dieback (cm) | 95** | .99** | -.97** | -.98** | -.80* | -.79* | -.99** | -.99** | -.93** | -.98** |
| Number new shoots | -.73 | -.76* | .80* | .80* | .75 | .70 | .77* | .77* | .50 | .62 |
| Total length new shoots (cm) | -.72 | -.78* | .81* | .81* | .83* | .79* | .80* | .80* | .52 | .64 |
| Average new shoot length (cm) | -.79* | -.87** | 89** | .89** | .89** | .87* | .89** | .88** | .65 | .76* |
| Number new leaves | - 83* | -.95** | 98** | .97** | .85* | .90** | .95** | .96** | .73 | .86* |
| Total length new leaves (cm) | -.75 | -.91** | .93** | .92** | .92** | .91** | .91** | .92** | .67 | .81* |
| Average new leaf length (cm) | -.89** | -.98** | .96** | .96** | *.92** | .84* | .99** | .99** | .86* | .95** |
| Dry weight new shoots+leaves (g) | -.78* | -.91** | .94** | .94** | .88** | .85* | .91** | .93** | .67 | .82* |
| B Root response in RGP test | | | | | | | | | | |
| Number new roots | -.80* | -.87* | .40** | .40** | .82* | .82* | .88** | .88** | .62 | .75 |
| Total length new roots (cm) | -.78* | -.85* | .89** | .88** | .78* | .82* | .85* | .85* | .58 | .71 |
| Average new root length (cm) | -.96** | -.97** | .96** | .97** | .72 | .75 | .97** | .97** | .90** | .95** |
| Total area new roots ($cm^2$) | -.80* | -.88** | .92** | .92** | .80* | .83* | .88** | .89** | .62 | .76* |
| Average new root area ($cm^2$) | -.89** | -.95** | .97** | .97** | 73 | .74 | .94** | .95** | .80* | .90** |
| Dry weight new roots (g) | -.68 | -.80* | .87* | .86* | .71 | .85* | .80* | .81* | .49 | .65 |
| Decay in upper taproot (%) | 72 | 92** | -.97** | -.96** | - 73 | -.92** | -.89** | -.92** | -.66 | -.82* |
| Decay in lower taproot (%) | .85* | 98** | -.999** | -.996** | -.79* | -.89** | -.97** | -.98** | -.80* | -.91** |
| C Seedling characteristics | | | | | | | | | | |
| Shoot length (cm) | 75 | .61 | -.23 | -.37 | -.60 | -.57 | -.68 | -.61 | -.57 | -.59 |
| Shoot basal diameter (cm) | - 75 | - 89** | .97** | .86* | .91** | .91** | .73 | .84* | .89** | .88** |
| Height/diameter ratio | .94** | 81* | - 60 | -.51 | -.82* | -.79* | -.84* | - 80* | -.75 | -.77* |
| Shoot dry weight (g) | .03 | - 24 | .26 | .28 | -.53 | .43 | .25 | .27 | .09 | .23 |
| Root dry weight (g) | -.27 | - 53 | 54 | 52 | 73 | .77* | .54 | .55 | .37 | .47 |
| Total dry weight (g) | -.19 | - 47 | .70 | .70 | .48 | .49 | .31 | .43 | .48 | .46 |
| Shoot/root dry wt ratio | 59 | .72 | - 70 | -.70 | - 66 | - 84* | -.73 | - 71 | -.65 | -.68 |
| Shoot xylem water potential (-kPa) | .89** | 96** | - 94** | - 94** | -.77* | -.73 | -.96** | -.96** | -.94** | -.94** |
| Root xylem water potential (-kPa) | 64 | 72 | - 78* | -.77* | - 74 | -.66 | -.73 | -.74 | -.42 | -.58 |
| Root starch concentration(%) | -.40 | -.61 | 58 | .57 | .57 | .76* | .60 | .60 | .59 | .62 |

[1] * = significant at 5% level. ** = significant at 1% level

Althen (1980) found that RGP was also strongly correlated with shoot xylem water potential. Because the respective measurements were performed on separate seedling samples in our study, we ran simple correlations between shoot xylem water potential and 15 RGP response variables. The correlation coefficient for number of new roots, the variable used by Webb and von Althen (1980), was not significant, but average new root length and area were strongly correlated (table 5).

The weak relationship between seedling root starch concentration and field performance is similar to our previous findings (Rietveld and Williams 1982). It appears that stored starch is not a key variable affecting field survival and growth, unless it is severely depleted or seedlings are transplanted into unusually stressful environments.

We also identified early field growth response variables that were indicative of eventual establishment and growth. Days to bud burst and terminal shoot tip die-back, which can be measured early in the first growing season, were strongly correlated with the remaining growth response variables measured at the end of the first and second growing seasons in the field (table 3). These highly significant correlations, presented in table 6, should be interpreted with the understanding that the relationships may be quite different if major weather changes occur during the planting year. The correlations are much stronger with seedling growth than with seedling survival. This is expected because black walnut seedlings typically survive tenaciously but grow poorly if planting stock quality or growing conditions are suboptimal.

Several investigators (e.g., Stupendick and Shepherd 1979, Sutton 1983) have found that excessive among-seedling variation in root regeneration tests makes it very difficult to use root growth variables to evaluate planting stock quality and predict field performance. The variation may be related to the genetic diversity of normal bed-run planting stock, and variation due to such factors as edge effects, speed of germination, bed density, and presence of diseases. Nambiar and Cotterill (1982) compared RGP of eight open-pollinated families of radiata pine (Pinus radiata D. Don) at three temperatures. They found that root regeneration characters were highly heritable and interacted significantly with temperature. We submit that other investigators interested in measuring planting stock quality should consider the following: 1) utilize genetically uniform plant materials or larger (25-50 seedling) sample sizes, 2) exploit genetic differences in root regeneration and root configuration to improve survival and initial growth; and 3) consider adopting other less variable and more easily measured factors (such as shoot basal diameter, xylem water potential, and shoot growth variables in RGP tests) that are strongly related to field performance. Several such variables identified in this paper should receive additional scrutiny.

As in many field studies reported in the literature, the expression of treatment effects

Table 5.--Simple correlations between root growth potential variables and shoot xylem water potential. Correlation coefficients are based on 6 pairs of sample means representing the packaging/overwintering treatments. For significance at $P \leq 0.05$ and 0.01, r values of 0.754 and 0.874, respectively, are required.

| Response variable in RGP test | Shoot xylem water potential (-kPa) |
|---|---|
| Time to bud burst (days) | -.31 |
| Terminal shoot dieback (cm) | .97**[1] |
| Number of new shoots | -.59 |
| Total length new shoots (cm) | -.61 |
| Average new shoot length (cm) | -.73 |
| Number of new leaves | -.86* |
| Total length new leaves (cm) | -.82* |
| Average new leaf length (cm) | -.95** |
| Dry weight new shoots + leaves (g) | -.84* |
| Number of new roots > 1.0 cm | -.72 |
| Total length new roots > 1.0 cm | -.69 |
| Average new root length (cm) | -.93** |
| Total area new roots > 1.0 cm ($cm^2$) | -.75 |
| Average new root area ($cm^2$) | -.91** |
| Dry weight new roots (g) | -.64 |

[1] * = significant at 5% level; ** = significant at 1% level.

Table 6.--Simple correlations between initial field growth responses and responses measured at the end of the first and second growing seasons. Correlation coefficients are based on six pairs of sample means representing the packaging/overwintering treatments. For significance at $P \leq 0.05$ and 0.01, r values of 0.754 and 0.874, respectively, are required.

| Initial growth response variable | First-year survival (%) | Second-year survival (%) | First-year terminal shoot growth (cm) | First-year lateral shoot growth (cm) | First-year net height growth (cm) | First-year net diameter growth (cm) | Second-year net height growth (cm) | Second-year net diameter growth (mm) |
|---|---|---|---|---|---|---|---|---|
| Time to bud burst (days) | -.76*[1] | -.61 | -.94** | -.92** | -.94** | -.94** | -.87** | -.89** |
| Shoot tip die-back (cm) | -.83* | -.84* | -.99** | -.99** | -.90** | -.97** | -.99** | -.99** |

[1] * = significant at 5% level; ** = significant at 1% level.

in this study was constrained by unusually favorable testing conditions. Under these conditions, only the weakest treatments would be expected to fail. But under more stressful conditions, smaller differences in planting stock quality might be expected to result in larger differences in survival and growth.

## CONCLUSIONS

The principal conclusions of the study are summarized as follows:

1) Of the packaging and overwintering methods examined, seedlings totally enclosed or seedlings with only their roots enclosed in Kraft bags with a plastic liner showed the best root growth potential and field performance. Their growth responses were comparable with those of spring-lifted seedlings. Seedlings heeled-in overwinter or cold-stored with roots exposed were of lesser quality.

2) Simple correlations of 27 measured characteristics of planting stock at time of planting with 10 measured field growth response variables revealed 13 characteristics strongly correlated with first-year survival and height and diameter growth. Time to bud-burst and shoot tip die-back after outplanting are good early indicators of eventual survival and height and diameter growth.

3) Shoot xylem water potential is strongly correlated with several variables in RGP tests as well as with first-year survival and growth in the field, and it is much easier to measure than root growth potential.

4) Root growth responses in root growth potential tests are highly variable among seedlings, making it difficult to distinguish treatment differences. Other growth responses, e.g., days to bud-burst, terminal shoot dieback, and shoot and leaf growth, are less variable, easier to measure, and highly correlated to field survival and growth.

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# EARLY HEIGHT GROWTH INCREASED IN BLACK WALNUT-SILVER MAPLE INTERMIXTURES[1]

F.W. von Althen[2]

Abstract.--Black walnut was planted in alternate rows with silver maple, autumn olive, black locust or white pine in two plantations in southwestern Ontario. Best competition control and growth of black walnut occurred in silver maple-black walnut intermixtures at spacings of 2 m between rows and 1.5 m within rows. This mixture provided 90% competition control in the 4th year after planting and significantly increased 5-year height increment of black walnut. Silver maple intermixtures, however, reduced levels of foliar nitrogen in walnut in comparison with those in autumn olive intermixtures.

Key words: black walnut, silver maple, autumn olive, white ash, black locust, interplanting, competition control, height increment, foliar nitrogen content.

## INTRODUCTION

High timber value and acceptable growth on former farmland have made black walnut *(Juglans nigra* L.) a preferred species for afforestation in southwestern Ontario. However, the success of black walnut plantations has been variable because site requirements were not met, herbaceous competition was not controlled or trees were not sheltered from wind damage during the early years after planting. To improve plantation success, black walnut has been planted in mixture with other tree species. Interplanting with nitrogen (N)-fixing species such as black locust *(Robinia pseudoacacia* L.), European alder *(Alnus glutinosa* L. [Gaertn.]) or autumn olive *(Elaeagnus umbellata* Thunb.) has increased walnut growth through increased soil N, competition control and protection from wind (Schlesinger and Williams 1984). However, little research has been done with intermixtures of non-nitrogen fixing hardwood species. Interplanting with white pine *(Pinus strobus* L.) has had limited success (von Althen and Nolan 1988). To determine the potential of silver maple *(Acer saccharinum* L.) as a nurse species for black walnut, two studies were carried out in southwestern Ontario. This report presents the 5-year results.

## METHOD

Two studies were established on former agricultural land near Parkhill, in Ontario's Middlesex County. Study 1 was a non-replicated pilot study that consisted of four plots of 0.33 ha each. The soil was a poorly drained Parkhill loam (Richards and Morwick 1952) 70 to 80 cm deep with a pH and organic matter content of the plow layer of 7.0 and 2.8%, respectively. The entire experimental area was plowed and disked in the autumn of 1981 and seedlings were machine-planted in April 1982 at a spacing of 3 m between rows and 1.5 m within rows. In the first plot, 693 1+0 black walnut were planted in 11 rows of 63 seedlings each. In the other three plots, 315 1+0 black walnut were planted in five rows, each containing 63 seedlings. Each row of walnut was surrounded on either side by rows of 63 seedlings (i.e., six rows in all) of one of the following species: 2+0 silver maple, 2+0 black locust, or 3+0 white pine (one species per plot).

Shortly after planting, and in April of the next two years, 6.0 kg/ha of active simazine were broadcast over the entire plantation area. Forks and lower branches of the walnuts were pruned during the third and fifth summers after planting.

Study 2 was laid out in a randomized block design with three replications of each of five treatments. The soil was an imperfectly drained Perth loam (Richards and Morwick 1952) 60 to 70 cm deep with a pH and organic matter content of the plow layer of 6.8 and 2.6%, respectively. After the harvest of corn *(Zea mays* L.), the field was plowed in November 1982 and tree and shrub seedlings were machine planted in April 1983.

Treatments consisted of: 1) black walnut in nine rows at a 3-m spacing between rows; 2) seven rows of silver maple alternating with six rows of walnut, with a 2-m spacing between rows; 3) five rows of silver maple alternating with four rows of walnut, with a 3-m spacing between rows; 4) as in treatment 3, but with white ash *(Fraxinus americana* L.) instead of silver maple; and 5) as

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in treatment 3, but with autumn olive instead of silver maple.

The stock used in study 2 was 1+0 walnut; other species were 2+0 stock. Trees were planted 1.5 m apart within each 25-tree row.

Competition control consisted of broadcast application of 3 kg/ha of active simazine over the entire plantation area shortly after planting and 4 kg/ha in April of each of the next two years. Forks and lower branches of black walnut were pruned during the third and fifth summers after planting. In July 1987, branches and secondary stems of the silver maple planted between the black walnuts at a spacing of 2 m (treatment 2) were pruned in half of each plot to open a space of approximately 80 cm between the crowns of black walnut and silver maple.

## DATA COLLECTION AND ANALYSIS

In both studies composition of the herbaceous vegetation was recorded each July and the intensity of competition was assessed by visual rating of the percentage of ground cover. Survival and total height of all planted tree and shrub species were recorded at the end of the first, third, and fifth growing seasons. The breast-height diameter (DBH) of walnuts planted in study 2 was also recorded at the end of the fifth growing season. Five composite foliage samples (two walnut leaves from each of five trees) were collected in each plot of study 2 in late July of the fifth growing season. All samples were analyzed for N content by the semi-micro Kjeldahl method.

The fifth year competition, survival, height, DBH and foliar N data from walnut in study 2 were subjected to analyses of variance and Tukey's test of significance.

## RESULTS

In study 1, broadcast applications of 6.0 kg/ha of active simazine shortly after planting and in April of the next two years provided 70-90% competition control in all plots in the first three years but greatly reduced the survival of black locust and white pine and of black walnut interplanted with black locust (Table 1). Competition control in year five ranged from 20% in the black walnut-white pine mixture to 90% in the black walnut-silver maple interplanting. The most common weed species were tall fescue *(Festuca arundinaceae* Schreb.), quack grass *(Agropyron repens* [L.] Beaur.), goldenrod *(Solidago* spp.), common milkweed *(Asclepias syriaca* L.), spiny annual sow-thistle *(Sonchus asper* [L.] Hill) and Canada thistle *(Cirsium arvense* [L.] Scop). Height increment of black walnut in the pure plantation and in the black walnut-silver maple mixture was similar, and was greater than in the black walnut-black locust or black walnut-white pine mixtures (Table 1).

In study 2, broadcast applications of 3 kg/ha of active simazine shortly after planting and 4 kg/ha in April of the next two years provided 60% competition control during the first three years, and an additional 10 to 20% of natural control was provided by shade from the interplanted silver maple (Table 2). Competition control in year 5 ranged from 40% in the pure black walnut and the walnut-ash mixture to 95% in the walnut-maple mixture planted at a spacing of 2 x 1.5 m. The most common weed species were tall fescue, quack grass, goldenrod and Canada thistle.

Five-year survival and DBH of black walnut differed little among treatments, but height increment was significantly higher in the walnut-maple mixture planted at 2 x 1.5 m than in the pure walnut planting or the walnut-ash or walnut-

Table 1.--Competition control and five-year survival and height increment in a pure black walnut plantation and in intermixtures of either silver maple, black locust or white pine with black walnut (study 1).

| Plantation mixture | Competition control in year | | Survival | | Height increment | |
|---|---|---|---|---|---|---|
| | 4 | 5 | Black walnut | Nurse species | Black walnut | Nurse species |
| | - - - (%) - - - | | - - - (%) - - - | | - - - (cm) - - - | |
| Pure black walnut | 50 | 50 | 99 | - | 314 | - |
| Black walnut - silver maple | 80 | 90 | 100 | 100 | 324 | 521 |
| Black walnut - black locust | 60 | 60 | 80 | 63 | 289 | 520 |
| Black walnut - white pine | 30 | 20 | 97 | 33 | 272 | 94 |

Note: Studies were not replicated, so no statistical analyses were done.

Table 2.--Competition control, five-year survival and height increment, DBH and foliar nitrogen concentrations in a pure black walnut plantation and in intermixtures of either silver maple, white ash or autumn olive with black walnut (study 2).

| Plantation mixture | Competition control in year | | Survival | | Height increment | | DBH | Foliar nitrogen |
|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | Black walnut | Nurse species | Black walnut | Nurse species | Black walnut | Black walnut |
| | - - (%) - - | | - - - (%) - - - | | - - - (cm) - - - | | -(cm)- | (% dry weight) |
| Pure black walnut 3 x 1.5 m spacing | 40 | 40a | 82a | - | 230a | - | 2.8a | 1.87ab |
| Black walnut - silver maple 2 x 1.5 m spacing | 90 | 95c | 83a | 96a | 323b | 473a | 2.9a | 1.78a |
| Black walnut - silver maple 3 x 1.5 m spacing | 80 | 90c | 83a | 98a | 267ab | 484a | 2.8a | 1.74a |
| Black walnut - white ash 3 x 1.5 m spacing | 40 | 40a | 86a | 91 | 237a | 339 | 2.9a | 1.95ab |
| Black walnut - autumn olive 3 x 1.5 m spacing | 50 | 60b | 82a | 91 | 230a | 231 | 2.8a | 2.07b |

Note: Means within columns followed by different letters differ significantly ($p < 0.05$).

olive mixtures (Table 2). Results of the foliar analyses suggest a deficiency in N (as defined by Finn [1966] and von Althen [1985]) in all walnuts except those planted in mixture with autumn olive (Table 2). The N content of leaves of black walnut planted in mixture with autumn olive was significantly higher than that of walnuts planted in mixture with silver maple.

## DISCUSSION

Black walnut is very demanding in its site requirements (Carmean 1966, Losche 1973) and is highly susceptible to the herbaceous competition that flourishes on good walnut sites during the early years after planting (Byrnes et al. 1973, von Althen 1985). Competition control has therefore become standard practice in walnut plantation establishment. However, annual weed control is expensive and becomes more difficult to apply as the trees grow larger. After the first two or three years, the established seedlings are expected to provide their own weed control through shading. However, black walnut has a relatively thin foliage and the shade cast is insufficient to retard the invasion of weed species after the artificial weed control treatments are discontinued, as shown by my data for the pure walnut plots.

Young black walnuts are also highly susceptible to mechanical damage by wind or rain. The long, tender shoots, with numerous, large compound leaves, are easily broken off in early summer before they are lignified (Schneider et al. 1968, Burke and Williams 1973).

To improve natural competition control and to provide greater protection against mechanical damage, black walnut has been planted in mixture with various nurse species. Interplanting black walnut with N-fixing tree and shrub species such as black locust, European alder or autumn olive has increased walnut growth through improved soil N supply and better competition control (Clark and Williams 1979, Ponder et al. 1980, Friedrich and Dawson 1984).

In Ontario, over 200 mixed plantations of black walnut and white pine have been established according to a prescription by Johnston (1979). The objectives of this prescription are fourfold: (1) to shade out the herbaceous vegetation, thereby increasing the available soil moisture and nutrients; (2) to deprive meadow voles *(Microtus pennsylvanicus* Ord.) of cover and food and prevent voles from girdling young walnut trees (Radvanyi 1974, 1975); (3) to decrease damaging winds, shade out the lower branches of the walnuts, and force walnut height growth; and (4) to stimulate juglone production as a built-in thinning mechanism 25 to 30 years after planting.

Some excellent plantations were established according to the Johnston (1979) prescription, but walnut growth was lower than expected in the majority of plantations (von Althen and Nolan 1988). Although many factors contributed to disappointing growth, competition control was identified as the most important. The main problem appears to be inadequate shading because of slow juvenile height increment of white pine. In the year of planting, height increment of black walnut generally does not exceed a few centimetres, but

beginning in year two, black walnut is capable of growing up to 1 m per year. In contrast, white pine has a much lower rate of juvenile height increment and generally requires 4-5 years to obtain a height of 1.5 m (Horton and Bedell 1960). If artificial competition control is discontinued after three years, the white pine are generally unable either to provide the competition control required to prevent invasion of weed species or to protect the walnuts from wind damage. This was confirmed by the results of study 1.

In the present paper, the potential of silver maple as a nurse species for black walnut was investigated because silver maple exhibits: (1) good growth on all walnut sites; (2) high juvenile growth rate; (3) dense foliage that provides shade for excellent competition control; (4) relatively high tolerance of simazine (von Althen 1979); (5) ease of culture in the nursery; and (6) minimal tendency to spread. Its disadvantages are poor stem form and faster juvenile growth than black walnut.

In study 1, high mortality of black locust and white pine was caused by simazine poisoning (Table 1). Although both species normally tolerate dosages of 6 kg/ha of active simazine (von Althen 1979), a heavy rain one day after application washed simazine into a slight depression of the near-level field and thereby increased the simazine concentrations in this area. This was made evident by the near absence of ground vegetation in the depression during the first summer and the greater-than-normal growth of competition in the remainder of the plot. The low survival of black walnut interplanted with black locust has not been explained. The superior height increment of black walnut planted in mixture with silver maple is believed to be the result of excellent weed control in combination with the forcing of walnut height growth by strong competition for light from the interplanted maples. The slow growth of black walnut in mixture with white pine is believed to be the result of inadequate competition control and the failure of the white pine to force walnut height growth (Table 1).

After discontinuation of the chemical competition control, the pure walnut, the walnut-ash and the walnut-olive mixtures in study 2 were invaded by broadleaved weeds and grasses during the fourth year; in contrast, shade from the tall silver maples maintained or improved competition control. Since black walnut grows poorly in the presence of herbaceous competition, the significant growth improvement of black walnut interplanted with silver maple is assumed to have been largely the result of competition control. However, walnut height increment was no doubt also influenced by competition for light from the interplanted maples. This competition forced walnut height growth, and reduced the size of branches on the lower bole of the walnuts.

After 5 years silver maple was 150 to 200 cm taller than walnut and had started to shade the walnut interplanted at the 2 x 1.5 m spacing (treatment 2). Removal of branches and secondary stems of silver maple provided added growing space but it remains to be seen if walnut will be able to maintain its height in relation to that of silver maple. If silver maple increases its height advantage further, it may be necessary to lop the tops of the trees.

Previous studies have shown that rapidly growing walnut trees have a foliar N content of over 3% (Finn 1966, Maeglin et al. 1977, Pope et al. 1982, von Althen 1985). An N content of between 2.5 and 3% indicates adequate supply of this nutrient, between 2 and 2.5% a possible N deficiency, and below 2% a definite nitrogen deficiency and probably serious stress. The significant difference between levels of foliar N of walnuts planted in mixture with autumn olive and silver maple suggests a soil N enrichment by autumn olive and an impoverishment by silver maple.

The N-fixing ability of autumn olive and its beneficial effect on walnut growth are well documented (Funk et al. 1979; Ponder 1980, 1983; Friedrich and Dawson 1984). The spreading form of autumn olive also provides soil shading and competition control. In study 2, competition control by autumn olive was inferior to that of silver maple but better than that provided by either pure walnut or the walnut-ash mixture (Table 2). Because total heights of black walnut and autumn olive were nearly equal, the olive provided adequate protection against wind damage. The greatest disadvantage of planting autumn olive is its spread to adjacent areas. Planting of autumn olive is therefore prohibited in some regions.

Interplanting black walnut with white ash is appealing because white ash is a valuable species and an excellent substitute for walnuts that fail to produce good-quality stems. At the end of the fifth growing season, white ash was 1 m taller than black walnut. Consequently, the walnuts were well protected from damage by wind but the characteristically long, narrow crowns of the young white ash provided only limited shade and, therefore, relatively poor competition control.

## SUMMARY AND CONCLUSIONS

Planting black walnut in alternate rows with silver maple provided excellent natural competition control and protection from damage by wind. Interplanting black walnut and silver maple at a spacing of 2 m between rows and 1.5 m within rows significantly increased the 5-year height increment of black walnut and reduced the size of branches on the lower bole. However, because the walnuts were threatened with suppression, the interplanted silver maples had to be pruned severely in the fifth year after planting. Interplanting black walnut with autumn olive significantly increased foliar N content over that of walnut interplanted with silver maple. A longer period of observation is required to determine the potential of silver maple as a nurse species for black walnut.

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# HORMONE FLUCTUATIONS DURING STRATIFICATION AND GERMINATION OF BLACK WALNUT SEED[1]

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Abstract.--Seeds collected from each of five black walnut trees were removed from cold stratification at 30 day intervals and dissected into endocarp, cotyledon and embryonic axis. Methanol leachates from each tissue were partitioned against ethyl acetate at pH 2.5 and 8.0. GC (gas-liquid chromatography) and GC-MS (gas-liquid chromatography-mass spectrometry) were used to quantify compounds co-eluting with ABA, $GA_3$, $GA_{4/7}$, t-zeatin and zeatin riboside.

The highest concentrations of GA's during the first 60 days of stratification were found in the embryonic axis. Abscisic acid concentrations were highest in the embryonic axis, but only during later stages of stratification. Cytokinins appeared to play a permissive role in germination only during the later stages of stratification. Some variation in plant growth regulators in seed from different trees were also observed.

## INTRODUCTION

Black walnut (Juglans nigra L.) is one of the most highly prized native hardwoods found in the Central Hardwoods region. Black walnut wood exports represented 4 percent of the total U.S. hardwood volume exported in 1983, but 11 percent of the hardwood export value (McCurdy and Kung, 1985). Thus, black walnut had the highest value of any hardwood species exported averaging $2293.00 per thousand board feet.

The diverse uses of this species and its high value to local and export markets have encouraged the frequent planting of black walnut. Unpredictable seed germination can affect success of direct seeded plantations or supplies of nursery stock. There is a need to obtain a more complete description of factors regulating black walnut seed dormancy to consistently improve germinative capacity.

The seed of Juglans sp. are considered to have a dormant embryo (Brinkman, 1974). Although walnut seeds are morphologically mature, a stratification period (cold, moist storage) is required during which time germination inhibitors decrease or stimulators increase. The suggested stratification period is 90 to 120 days with a 50 percent germinative capacity (Brinkman, 1974).

[1]Paper presented at the Seventh Central Hardwood Forest Conference. [Carbondale, IL, March 5-8, 1989].

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The occurrence of compounds with the potential to regulate seed dormancy has been investigated for many seeds including the Juglans species. Martin et al. (1969) found no GA's in the kernels of Juglans regia seed, but did identify an ABA-like inhibitor that decreased during cold stratification. Meier (1979) reported the presence of ABA in black walnut seed, but no quantitative measurements during stratification were recorded.

Seed dormancy mechanisms are apparently species specific. The purpose of this research was to characterize, for the first time, the change in hormone concentrations in black walnut seed tissues during the stratification process.

## MATERIALS AND METHODS

Mature seed were collected from under 5 trees located throughout Jackson County, Illinois. After mechanically removing the pericarp (fleshy outer portion, or husk), seed from each half-sib family were placed in water to remove floaters. Cleaned seed (200-500) from each family were stored in 4 mil plastic bags inside burlap bags. Seed were cold stratified at 4°C ± 1°C for 180 days, then removed from storage and placed at ambient temperatures for 30 additional days.

### Tissue Extraction for Chemical Analysis

At 30 day intervals, 50 sound seed from each family were removed from stratification and opened. If there was no evidence of tissue deteriorati ı, the seed were considered viable. The embryonic axis and some of the cotyledon and endocarp (shell) tissues from 25 sound seed were removed and immediately placed into 80% methanol/water ($MeOH:H_2O$, v:v). A solvent and standards blank, prepared by adding 2 ml of 10 mM stock solution of $GA_3$, $GA_{4/7}$, c-ABA, IAA, and t-zeatin

to 25 ml of 80% MeOH, were treated identically to the tissue samples. The tissues were placed on a shaker in a cold (4°C) storage room. After 24 and 48 hours, the tissues were re-extracted with fresh, cold 80% MeOH (100 ml for endocarp and cotyledon tissue, 25 ml for embryonic axis tissue). This process leached free plant growth regulators from the tissues through three changes of 80% MeOH and avoided the usual problem of "cleaning up" complex plant tissue samples which occur when a homogenization step is included (Frankland and Wareing, 1966; Martin et al., 1969; Mann and Jaworski, 1970).

In our experiment, all glassware was acid washed with a solution of concentrated $H_2SO_4$ and No-Chromix (Godax Laboratories Inc.) for 4-12 hours, rinsed six times with distilled, deionized water, and then dried at 120°C. All containers and vials were capped with aluminum or teflon lined caps.

The methanolic samples were evaporated in a Buchler rotary evaporator at 35° ± 5° C under vacuum to remove the MeOH. The remaining extract was frozen at -80°C and then immediately lypholized. The lypholized extracts were stored at -4°C until all samples were collected. Samples from all tissues, stratification lengths, and families were randomized before hormone analyses were begun.

### Hormone Extraction and Analysis

The lypholized cotyledon and endocarp samples were rehydrated with 25 ml of deionized water (Millipore, Milli-Q system), and the embryonic axis samples were rehydrated with 10 ml of deionized water. The rehydrated samples were then partitioned against an equal volume of HPLC grade ethyl acetate at pH 2.5, then pH 8.0 (Figure 1). Both EtOAc fractions were dried under a stream of dry $N_2$, solubilized in 100 µl of pyridine, and then silyated with 200 µl of BSA (N,O-bis,(trimethylsilyl)acetamide).

Quantitative hormone analysis was performed by injecting 1.0 or 3.0 µl of the silyated sample onto a dual column gas chromatograph (Varian model 3700) equipped with flame ionization detectors. The columns, 180cm x 2.0 mm (id), were packed with OV-1 (methyl silicone) or OV-17 (methyl, phenyl silicone) on 100/120 mesh Gas Chrom Q. Column temperature was programmed from 150°C to 250°C at 8°$min^{-1}$ or 210°C to 280°C at 6°C $min^{-1}$ for acidic and basic samples respectively, using a $N_2$ flow rate of 40 ml $min^{-1}$. Duplicate samples of each fraction were run on each column. Chromatographic signals were recorded on a Shimadzu (model CR1-B) integrator/recorder to determine area of peaks co-eluting with hormone standards within a retention time window of 5%.

The internal standards (IS) added to all acidic EtOAc and basic EtOAc samples before drying with $N_2$ were androsterone (5-alpha-androstan-3 alpha-ol-17-one) and testosterone (17 beta-hydroxyandrost-4-en-3-one), respectively.

The ratio ($k_i$) of hormone concentrations from the standards sample for the OV17 and OV1 columns was calculated as follows:

$$k_i = \frac{A_i}{B_i}$$

where:

$A_i$ = concentration of hormone i on column OV17
$B_i$ = concentration of hormone i on column OV1

Similar calculations were done for tissue samples. A t-test was used to determine if the $k_i$ ratio of the standard and the tissue samples were significantly different. For each hormone, where the $k_i$ ratio was significantly ($\alpha = 0.05$) greater than the standards samples $k_i$, the results from the OV1 column were reported (the result suggested more contaminants were co-eluting with the hormone on the OV17 column). Conversely, if the $k_i$ ratio was smaller, the results from the OV17 column were reported. Results from the OV1 column were reported for c-ABA and $GA_{4/7}$ and from the OV17 column for $GA_3$ and IAA. The mean of the OV1 and OV17 columns were used to report the values for t-zeatin and t-zeatin riboside because there was no significant difference in the $k_i$ ratio for these two plant hormones.

### Gas Chromatography-Mass Spectrometry

Standards and plant tissue samples were prepared as outlined above. Mass spectra for eluting compounds were recorded on a Finnigan Model 3000 quadrupole MS equipped with a Finnigan Model 9500 GC using a 150cm (2mm id) column packed with 3% OV17 on 100/120 mesh Gas Chrom Q. Retention times and spectral lines from tissue samples were compared visually to spectral lines obtained from standard samples.

## RESULTS AND DISCUSSION

### Hormone Quantitative Methods

Percent recoveries of hormones added to standard samples ranged from 27 to 54 percent (Table 1). Recoveries were highest for ABA and the GA's. IAA was not recovered from 75% of the samples because the amount was below the detection limit. The basic fraction had low percent recoveries; however, chromatograms from tissue samples were less complex than those from the acidic fraction so that t-zeatin and t-zeatin riboside could be detected in the tissue samples. The spectral pattern from GC-MS for t-Zeatin from tissue samples matched that

Table 1.--Mean percent recovery of each plant growth regulator added to 28 standard samples.

| Standard | Amount Added to Standard (µg/µl) | % Recovery ± Std. Error |
|---|---|---|
| Acidic Fraction | | |
| IAA | 350/300 | 28 ± 6 |
| c/t-ABA | 530/300 | 44 ± 4[1] |
| $GA_3$ | 690/300 | 54 ± 5 |
| $GA_{4/7}$ | 660/300 | 51 ± 3 |
| Basic Fraction | | |
| t-Zeatin | 440/300 | 27 ± 4 |

[1]Calculated as sum of cis and trans isomers. Approximately 6% of cis form was converted to trans form during sample handling.

Separate tissues from seeds of five families
after 0, 60, 120, 180 and 210 days
(endocarp, cotyledon, embryonic axis)

Standard Blank ---> 3 X 80% MeOH in cold (4 C) <-- Solvent Blank

Evaporate MeOH
under vacuum at 35°C

Lypholize for storage at -4°C

Rehydrate with deionized water

Adjust pH to 2.5

Partition 3x against EtOAc

Aqueous phase

Adjust pH to 8.0

Discard aqueous phase <-- Partition 3x against EtOAc

Reduce to < 4.0 ml
under vacuum
at 35°C

Add 1.0 ml of
1.4 mM Testosterone

Evaporate to dryness
with dry $N_2$

Solubilize in 100 µl
pyridine

Add 200 µl BSA

gas chromatography

2 x OV-1 2 x OV-17

EtOAc phase

Reduce to < 4.0 ml
under vacuum
at 35°C

Add 1.0 ml of 1.7mM
Androsterone

Evaporate to dryness
with dry $N_2$

Solubilize in 100 µl
pyridine

Add 200 µl BSA
warm @ 60°C (1 hour)
store overnight @ room temp

gas chromatography

2 x OV-1 2 x OV-17

Figure 1.--Flowchart identifying analytical procedures for extraction, purification and gas chromatography of black walnut seed hormones.

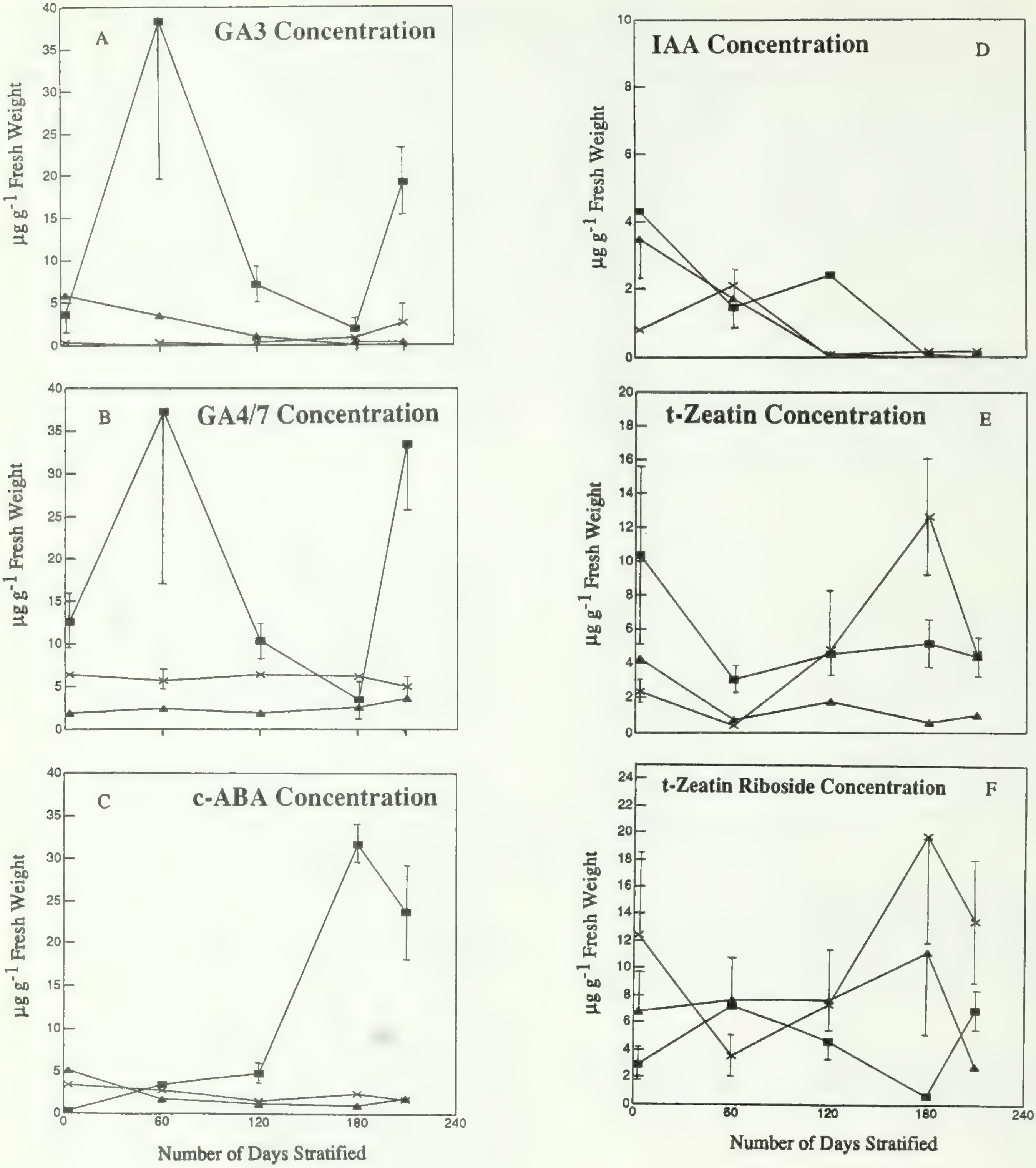
from the standard samples. Because of the number of overlapping chromatographic peaks in the acidic fractions, GC-MS identification of ABA and GA's was not conclusive. The mass spectra for both internal standards (androsterone and testosterone) from the tissue samples matched those from the standard sample.

Percent recoveries reported in the literature range from 10% to 90% for indole-3-acetic acid (IAA) and 59% to 93% for abscisic acid (Brenner, 1979). When quantifying plant growth regulators extracted from natural sources, most of the loss occurs before introducing the sample into the analytical instrument.

## Seed Tissue Hormone Levels

The embryonic axis responds to cold stratification during the first 60 days with an increase in compounds eluting at retention times the same as $GA_3$ and $GA_{4/7}$ (figs. 2A and 2B). After 60 days of stratification, there was a significant decrease in GA's in the embryonic axes. The concentration of GA's again increased in the embryonic axes when seed were removed from cold storage and allowed to begin the germination process (Day 180 to 210).

Black walnut seed dormancy and germination patterns conform well with the model developed by Khan (1975). After seed fall and before cold treatment, some seeds will germinate. Hormone balances resulting from maternal influence are most likely responsible for this phenomenon. However, when the seed are subjected to cold temperatures, none of the seed will germinate until the appropriate endogenous hormone balance has been achieved. Some seeds may germinate after 60 days of stratification, when GA levels have increased in the embryonic axis. During protracted stratification, on the other hand, ABA concentration in the embryonic axis increases and this apparently reduces further growth of the axis. As predicted by Khan's model, an increase in the cytokinin concentration in the cotyledons could have a "permissive" role and allow germination and growth in the presence of elevated ABA levels should environmental factors become favorable.




Figures 2A through 2F - Concentration of plant growth regulators in the embryonic axes (■——■), the cotyledon (×——×), and the endocarp (▲——▲) of black walnut seed during stratification (days 0 to 180) and germination (days 180 to 210). Bars represent the standard error of the mean for points with standard errors larger than the symbol.

In the cotyledons, the $GA_3$ concentration was below the analytical detection limit until after 120 days of stratification (fig. 2A). However, $GA_{4/7}$ had a constant concentration of 6 $\mu g\ g^{-1}$ fresh weight (FW) throughout the stratification period (fig. 2B). The GA's act as promoters of food reserve hydrolysis in many seeds, this is consistent with ultrastructural studies on black walnut seed which show a continual disappearance of protein and lipid in cells throughout the stratification period (authors unpublished data).

ABA concentration increased in the embryonic axes, but not in the cotyledons (fig. 2C). An increase of ABA late in the dormancy period has been observed in Latuca (Bex, 1972), Sinapis (Schopfer et al., 1979), and Haplopappus (Galli et al., 1980), where ABA may act as an inhibitor of cell expansion in the radicle tissue during late stages of dormancy. After 120 days of stratification, some black walnut seed will rupture the seed coat and begin radicle elongation in the cold; however, the epicotyl usually remains dormant or quiescent until a more favorable temperature is detected.

The role of ABA in black walnut embryonic axes may be to inhibit the growth of the epicotyl during late stages of stratification, when temperatures may not be favorable for epicotyl elongation.

The highest concentrations of IAA occurred before stratification began and generally decreased during stratification (fig. 2D). The decreasing concentration suggests that IAA is probably not involved in the stratification and germination processes within the seed.

There was a rapid increase in t-zeatin and t-zeatin riboside in the cotyledons near the end of stratification (figs. 2E and 2F). The increase in cytokinins in the cotyledons coincided with the rapid increase in ABA in the embryonic axis. Both zeatin and zeatin riboside can substitute for low temperature afterripening in ash embryos (Tzou et al., 1973) and may be acting as "permissive" agents to germination in stratified black walnut seed. Cytokinins have been reported to promote hypocotyl elongation in watermelon seedlings (Loy, 1980) and could enhance black walnut germination after a period of stratification and in the presence of ABA.

Black walnut endocarp tissue showed a decline in all compounds co-eluting with identifiable plant growth regulators during the first 60 days of stratification (figs. 2A to 2F). Concentrations of hormones in this tissue were generally 5 to 10 times lower than in the cotyledons or embryonic axis. Concentrations of hormones in this non-living tissue are most likely a result of residual maternal influences or diffusion from living embryonic tissues.

Although there was insufficient replication to test family differences adequately, we have observed that differences among families may indeed exist. Within a black walnut seed population, there appears to be some half-sib progeny which are more or less responsive to environmental conditions which may break dormancy during a shorter period of stratification. This seems reasonable in the sense that survival may also depend on the ability to remain dormant during a short, favorable environmental cycle; however, progeny which germinate early (after shorter stratification) when climatic conditions continue to be favorable will have a competitive advantage over other species.

## CONCLUSIONS

Concentrations of hormones extracted from various seed tissues varied. Concentrations may range over a 1000 fold between tissues of the testa and embryonic axis. For seeds with a dormant embryo that is released after the stratification requirements are met, a promoter:inhibitor hormone relationship has often been found to control dormancy and germination.

Amen (1968) proposed a feedback model of seed dormancy which described the embryonic axis as the site of hormone production which affected enzyme function mainly in the food storage tissues. Similarly, Kelly (1969) reviewed ABA and GA regulation of seed dormancy and germination and concluded that hormones act as the functional components for a cybernetic system which is regulated through the hormonal balance between the embryonic axis and the food storage tissue. This may also be true for dormant black walnut seed, but these models do not fully account for seed which germinate before stratification or during stratification and then remain quiescent until environmental conditions are more favorable.

Probably the most thoroughly tested seed dormancy model is that of Khan (1975). This model compared the possible combinations of three classes of plant growth regulating compounds (GA's, ABA and cytokinins) and their potential effect on seed dormancy. Khan's model assigns a secondary role to inhibitors (e.g. ABA) and is consistent with much of the data reported for dormant and germinating seeds. In addition, this model accounts for germination in the presence of inhibitors (e.g. ABA) by assigning a "permissive" role to cytokinins, which antagonize the effects of inhibitors (Khan, 1971). Khan derived the model by observing that the presence or absence of a hormone or hormones was less important that the relationship between hormones. Khan suggested that there could be many intermediate physiological situations which could cause partial germination or maintain partial dormancy.

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# OAK REGENERATION BY CLEARCUTTING AFTER A SERIES OF PARTIAL CUTS[1]

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Abstract.--A gradual increase in the amount of crown opening with successive cuttings over a 30-year period evidently allowed ample time for the establishment, growth and survival of advance oak regeneration. One to five years following a final clearcutting there was oak regeneration on four poor to good sites surveyed. Oaks regenerated best on poorer sites with decreased competition.

## INTRODUCTION

In theory, the ideal method for regenerating oak is the shelterwood method (Merritt 1980). Other currently recommended methods of oak regeneration, such as clearcutting and group selection, often require advance regeneration to be present for successful stand establishment (Merritt 1980). For example, when adequate advance regeneration is not present in a mature stand, Sander (1977) recommends reducing overstory density to stimulate seed production prior to clearcutting. When applying the shelterwood method, several light cuttings rather than one heavy cut are preferable to maintain a denser canopy (Sander and Clark 1971), thereby suppressing the development of competing understory species. According to the criteria for advance oak reproduction suggested by Sander (1977), there should be at least 435 oaks per acre 4.5 feet tall or taller well distributed over the area to regenerate oak stands.

Use of the shelterwood method is rare in the central hardwood region, perhaps because optimal cutting sequences and densities have not been determined, compounded by the fact that oak species are notoriously poor seed producers (Merritt 1980). In order to add to the information on oak regeneration, we measured the regeneration of oak and other tree species following the application of a series of partial cuts and a final clearcut at Sinnissippi Forest, where forest managers switched from a single-tree selection method to the shelterwood method in the mid 1970's. Historical obsrvations on the forest had established that the single tree selection method and clearcutting not preceded by partial cuts were inadequate to secure oak regeneration on medium to good sites. Our objective was to describe oak regeneration after a series of cuttings including a final clearcut on four sites of varying quality.

## METHODS

This study was conducted in northeastern Illinois at Sinnissippi Forest, a 2200-acre, managed forest in Ogle County. The three major oak species in the forest are white oak (Quercus alba L.), northern red oak (Quercus rubra L.) and black oak (Quercus velutina Lam.). The forest had been heavily logged in the middle 1800's. The forest was grazed until the middle 1930's when the forest owners entered into a cooperative agreement for research and management with the Department of Forestry at the University of Illinois. During the 1940's and 1950's a series of improvement cuttings were instituted. Thinnings from both below and above eliminated defective trees and during the 1950's and 1960's sanitation cuttings, mostly in the poorer-quality black oak stands, were made removing oaks with symptoms of oak wilt and all other trees within a 50-foot radius of the diseased trees.

Four sites of varying productivity were selected for this study. Soils in this forest were developed in sands from Wis -nsin glacial outwash and in loessal material on sand and glacial till. Productivity classes ranged from a black oak stand of poor quality with a black oak site index of 50 to a stand with a red oak oak site index of 70 (50-year basis).

[1]Paper presented at the Seventh Central Hardwood Forest Conference, Carbondale, IL, March 5-8, 1989.

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A site that originally had 80% or more black oak stems with a black oak site index of 50 was classified as black oak poor (BOP). Chelsea Loamy Sand is the only soil type present. Soil classification in this paper is that of the USDA Soil Conservation Service. Slopes over 84% of the site ranged from 7-15% and the remaining 16% of the slopes were less than 7%. An improvement cutting in which defective trees were removed was made in 1955 reducing crown cover to 90%. Additional seed cuttings reduced the crown cover to 80% in 1965 and 60% in 1979. The final cut was made in 1984.

Two sites that originally had 50-79% mixed oak stems with oak site index values of 60 were classified as mixed oak medium (MOM). Mixed oak medium site 1 (MOM1) was the poorer of the two medium-quality sites. Soil types were 43% Chelsea Loamy Sand on slopes ranging from 7-15%, 24% Chelsea Loamy Sand on slopes ranging from 1-7% and 33% Boone Sand on 15-35% slopes. An improvement cutting was made in 1952 leaving 90% residual crown cover and was followed by additional cuttings in 1960, leaving 70% crown cover, and 1977, leaving 60% residual crown cover. The final cut was made in 1982.

The better of the mixed oak medium sites (MOM2) had 45% Lamont Sandy Loam on 5-12% slopes, 28% Martinsville Silt Loam on 10-15% slopes and 27% Boone Sand on 15-45% slopes. An improvement cutting was made in 1958, leaving 90% residual crown cover, followed by cuttings in 1972 and 1982 that left 70% and 60% crown cover residual, respectively. The final cutting was made in 1986.

A red oak good (ROG) site had 59% Martinsville Silt Loam on 2-5% slopes and 41% Eleva Sandy Loam on 2-7% slopes. The site originally had 80% or more red oak stems and a red oak site index of 70. A light improvement cutting was made in 1958, leaving 90% residual crown, followed by a cutting in 1974 leaving 70% residual crown and a final cutting in 1983.

The four sites averaged 7 and ranged from 3 to 11 acres in area. At the final cutting all large timber was removed, although some small trees up to 20 feet in height were not damaged by logging and were left on the site. Most stems of the advance regeneration were severed by logging equipment, resulting in a preponderance of seedling and sapling sprouts. A small sample of ten, square milacre plots were randomly located in each stand during July of 1987. Sample size was restricted owing to the limited time and manpower available for the study. All woody stems less than 4 inches diameter at breast height and small trees and shrubs less than breast height (4.5 feet) in each plot were counted by species and visual estimates of the percentage cover by each woody plant species were made. Tree heights were measured and estimates were also made of the percentage of each plot covered by grasses, herbaceous plants, woody vines and brambles.

## RESULTS AND DISCUSSION

Oak regeneration from 1 to 5 years after the final cutting ranged from 5600 stems per acre on the black oak site to 1400 total stems per acre on the red oak site (Table 1). Most oak stems observed were seedling and sapling sprouts. Oaks were a major component of tree regeneration greater than 4 feet in height only on the poorer sites (BOP and MOM1) (Table 2). Heights of oak reproduction were variable, but on the poor and medium sites, more oaks tended to overtop competing vegetation than on the good site. Observations of other stands at Sinnissippi Forest reveal a contrasting pattern of oak regeneration in stands that have not had a series of partial cuts. Advance regeneration and regeneration of oaks following hardwood clearcutting on medium and better quality sites in Sinnissippi Forest tend to be almost totally absent in stands without a recent history of major canopy openings.

Table 1. Oak regeneration 1-5 years after final cutting on sites of varying quality. Mean values and relative frequencies are for 10 plots. Standard deviations are in brackets. The number of years since clearcutting are 3 for BOP, 5 for MOM1, 1 for MOM2 and 4 for ROG.

| Species | Site and Site Index | Mean No. of Stems/Plot | No. of Stems/Acre | Relative Frequency |
|---|---|---|---|---|
| *Quercus alba* | BOP 50 | 3.3 (3.9) | 3300 | 0.7 |
| | MOM1 60 | 0.9 (1.3) | 900 | 0.4 |
| | MOM2 60 | 2.6 (5.2) | 2600 | 0.4 |
| | ROG 70 | 0.7 (1.3) | 700 | 0.3 |
| *Quercus rubra* | BOP 50 | 0 | 0 | 0 |
| | MOM1 60 | 1.4 (1.7) | 1400 | 0.6 |
| | MOM2 60 | 1.1 (1.6) | 1100 | 0.5 |
| | ROG 70 | 0.7 (1.3) | 700 | 0.3 |
| *Quercus velutina* | BOP 50 | 2.3 (1.6) | 2300 | 0.8 |
| | MOM1 60 | 0 | 0 | 0 |
| | MOM2 60 | 0.1 (0.3) | 100 | 0.1 |
| | ROG 70 | 0 | 0 | 0 |

Table 2. Estimated numbers of stems per acre of oaks and other woody plant regeneration by height classes 1-5 years after final cutting on sites of varying quality at Sinnissippi Forest. The number of years since clearcutting are 3 for BOP, 5 for MOM1, 1 for MOM2 and 4 for ROG.

| Site | Regen. type | Height Classes of Regeneration (feet) 0-4 | 4-8 | 8-12 | >12 |
|---|---|---|---|---|---|
| BOP | oaks | 4200 | 1200 | 100 | 100 |
| | other trees | 300 | 600 | 200 | 500 |
| | shrubs | 2100 | 1800 | 300 | - |
| MOM1 | oaks | 1100 | 700 | 300 | 200 |
| | other trees | 400 | 700 | 200 | 500 |
| | shrubs | 200 | 1500 | - | - |
| MOM2 | oaks | 2700 | 600 | 200 | 300 |
| | other trees | 400 | 800 | 600 | 500 |
| | shrubs | 600 | 500 | - | - |
| ROG | oaks | 1300 | 100 | - | - |
| | other trees | 1000 | 900 | 100 | 400 |
| | shrubs | 1700 | 900 | 100 | - |

The regeneration results from the four sites are not strictly comparable because the time since clearcutting varies from 1 to 5 years. The series of cuttings that preceeded the final cuts also occurred at different times, under different climatic regimes and at different times in relation to oak mast production cycles. An examination of table 1 reveals not only that there is more oak regeneration on the poorer quality sites, but also that an additional increment in quantity of oak regeneration seems to occur in the more-recently cut stands. In spite of the differences in timing of the treatments and the interval of time between final cutting and sampling, site quality seems to have been a stronger determinant of oak regeneration than timing of cuttings in relation to short-term climatic regimes and seed-production cycles.

The sum of cover percentages for all oak species on a site was 68% on the BOP site, 53% on the MOM1 site, 28% on the MOM2 site, and 14% on the ROG site (Table 3). Oak cover also constituted a smaller portion of total tree and shrub cover and total plant cover on the better sites (Table 3). The amount of foliar cover by oaks in the regeneration following the final cutting was inversely proportional to site quality. These results are consistent with those of Carvell and Tryon (1959) who found that oaks regenerated better on poorer sites with decreased competition from herbaceous vegetation and shrubs. The sum of foliar cover percentage estimates for herbaceous plants, grasses, brambles (raspberries, gooseberries and greenbriar) and vines in midsummer ranged from 128% on the BOP site to 240% on the ROG site (Table 3), illustrating the greater amount of competition on the good site.

It is possible that midtolerant red oak eventually will dominate initially-faster-growing trees, and develop its characteristically long, clear bole when growing for small canopy openings

Table 3. Mean cover percentages per plot for tree and shrub species and other vegetation (grasses, herbs, brambles and vines) 1-5 years after final cutting on sites of varying quality at Sinnissippi Forest. The number of years since clearcutting are 3 for BOP, 5 for MOM1, 1 for MOM2 and 4 for ROG.

| | Site and Site Index | | | |
|---|---|---|---|---|
| Species | BOP 50 | MOM1 60 | MOM2 60 | ROG 70 |
| Quercus alba | 31 | 21 | 12 | 5 |
| Q. rubra | 0 | 30 | 16 | 9 |
| Q. velutina | 37 | 2 | 1 | 0 |
| Carya ovata | 3 | 1 | 5 | 10 |
| C. cordiformis | 5 | 13 | 17 | 18 |
| Prunus serotina | 31 | 15 | 23 | 25 |
| P. virginiana | 7 | 3 | 0 | 4 |
| Ulmus spp. | 2 | 36 | 32 | 3 |
| Corylus americana | 10 | 8 | 6 | 9 |
| Cornus spp. | 15 | 3 | 7 | 15 |
| Others | 16 | 19 | 27 | 1 |
| Subtotal | 157 | 151 | 146 | 99 |
| Other vegetation | 128 | 159 | 171 | 240 |
| Total | 285 | 310 | 317 | 339 |

in dense mixed stands (Oliver 1978). However, on the red oak site our early regeneration survey results indicate the possibility that red oak and white oak will persist only as equal components with other tree species in the developing mixed hardwood stand rather than as the predominant forest species.

Standard deviation values (Table 1) suggest that any randomly-located milacre plot is just as likely to have no oaks, or on average about twice the number of oaks, as the mean value for oak stems in a plot. The relative frequencies for oak species are given in Table 1 and indicate clearly that the relative frequncy of occurence, or stocking, of oak regeneration in randomly distributed milacre plots declines as site quality increases. In addition, the species composition of woody plant regeneration differed markedly according to site quality. Northern red oak regeneration was found only on the good and medium quality sites and ranged from 700 stems per acre on a good site to 1400 stems per acre on a medium site (Table 1). Black oak regeneration occurred only on one MOM site with 100 stems per acre and the BOP site with 2300 stems per acre. White oak regeneration was present on all sites, but was more abundant on the poorer sites (Table 1).

Other trees and shrubs varied in occurence with site quality (Table 4). Bitternut hickory (Carya cordiformis [Wangenh.] K. Koch) and shagbark hickory (Carya ovata [Mill.] K. Koch) were most abundant on the better sites. Black cherry (Prunus serotina Ehrh.) occurred on all sites while chokecherry (Prunus virginiana L.) was prevalent on poorer sites. Hazelnut (Corylus americana Walt.) and several small species of the genus Cornus combined constituted the most common shrub group on all sites.

Grape vines (Vitis spp.) were more abundant on the better-quality sites. The greatest amount of low vegetative cover, proportionately, on all sites was for black raspberry (Rubus spp.), Virginia creeper (Parthenocissus quinquefolia [L.] Planch.), gooseberries (Ribes spp.) and poison ivy (Toxicodendron radicans [L.] Kuntze.).

The amount of oak regeneration measured after clearcutting in this study is much less than the advance regeneration present prior to the final cutting in other Sinnissippi Forest stands of identical quality and similar cutting treatments (Ehlert et al. 1987). This suggests that there is considerable loss of oak reproduction associated with harvesting and opening of the stands to full sunlight.

Ehlert and coworkers (1987) measured regeneration in 1986 in the same stands sampled in 1987 for this study. Between 1986 and 1987 the overall patterns of oak regeneration described in the two studies remained the same. The sample and plot sizes were the same in both studies, although different sets of plots were randomly-located for each study. The similarity

Table 4. Regeneration of woody species other than oaks 1-5 years after final cutting on sites of varying quality. Mean values and relative frequencies are for 10 plots. Standard deviations are in brackets. The number of years since clearcutting are 3 for BOP, 5 for MOM1, 1 for MOM2 and 4 for ROG. Included among others are trees and shrubs, as in table 2, plus vines and branches.

| Species | Site and Site Index | Mean No. of Stems/Plot | No. of Stems/Acre | Relative Frequency |
|---|---|---|---|---|
| Carya ovata | BOP 50 | 0 | 0 | 0 |
| | MOM1 60 | 0 | 0 | 0 |
| | MOM2 60 | 0.3 (0.5) | 300 | 0.3 |
| | ROG 70 | 0.4 (0.5) | 400 | 0.4 |
| C. cordiformis | BOP 50 | 0.1 (0.3) | 100 | 0.1 |
| | MOM1 60 | 0.1 (0.3) | 100 | 0.1 |
| | MOM2 60 | 0.2 (0.6) | 200 | 0.1 |
| | ROG 70 | 0.3 (0.5) | 300 | 0.3 |
| Prunus serotina | BOP 50 | 1.7 (3.2) | 1700 | 0.5 |
| | MOM1 60 | 0.2 (0.4) | 200 | 0.2 |
| | MOM2 60 | 0.4 (0.9) | 400 | 0.2 |
| | ROG 70 | 1.0 (1.6) | 1000 | 0.4 |
| P. virginiana | BOP 50 | 0.6 (1.0) | 600 | 0.3 |
| | MOM1 60 | 0.1 (0.3) | 100 | 0.1 |
| | MOM2 60 | 0 | 0 | 0 |
| | ROG 70 | 0.1 (0.3) | 100 | 0.1 |
| Ulmus spp. | BOP 50 | 0.1 (0.3) | 100 | 0.1 |
| | MOM1 60 | 0.9 (0.8) | 900 | 0.6 |
| | MOM2 60 | 0.5 (1.0) | 500 | 0.2 |
| | ROG 70 | 0.1 (0.3) | 100 | 0.1 |
| Cornus spp. | BOP 50 | 3.3 (4.5) | 3300 | 0.4 |
| | MOM1 60 | 0.2 (4.0) | 200 | 0.2 |
| | MOM2 60 | 1.0 (2.8) | 1000 | 0.2 |
| | ROG 70 | 2.0 (3.0) | 2000 | 0.4 |
| Others | BOP 50 | 1.8 | 1800 | 0.8 |
| | MOM1 60 | 2.1 | 2100 | 0.7 |
| | MOM2 60 | 2.0 | 3300 | 0.6 |
| | ROG 70 | 1.2 | 1200 | 0.7 |

of results obtained in subsequent years strengthens the likelihood that the oak regeneration estimates of this study are reasonable, in spite of the small sample size. There was a general decline in the number of oak stems from 1986 to 1987, while the estimated percentages of cover increased or remained constant for all oak species including red oak, which doubled in estimated cover. With the small sample size, this could have been a chance result of sampling. However, such a pattern is consistent with the idea that high initial mortality immediately after harvest may be followed by a more-gradual decline in oak reproduction numbers together with a gradual increase in oak crown cover as a portion of the oaks emerge above the tangle of competing low vegetation.

Cuttings in these stands were initially light and extended over a 30-year period, evidently allowing ample time and shelter for establishment, growth and survival of seedlings from the generally-poor and heavily-predated seed crops of oaks. Small, scattered openings resulting from oak-wilt sanitation cuttings, particularly on the poorer sites, may have further aided in the survival and growth of advance regeneration. The rather long time period over which the cuts were made, and the gradual increase in the amount of crown opening with successive cuttings may have contributed to the successful survival and growth of oak regeneration in these cases. These results provide a basis for comparison and further testing of cutting sequences, densities and intervals to obtain optimal systems for oak regeneration in central hardwood forests.

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# IMPACT OF PRODUCT MIX AND MARKETS ON THE ECONOMIC FEASIBILITY OF HARDWOOD THINNING[1]

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Chris B. LeDoux

Abstract.--Results demonstrate how the economic feasibility of commercial hardwood thinning is impacted by tree diameter, product mix, and primary product markets. These results indicate that multi-product harvesting can increase revenues by $\$0.01/ft^3$ to $\$0.32/ft^3$; and that small shifts in price levels or haul distance can postpone commercial thinning approximately 10 years.

## INTRODUCTION

The economic scarcity of quality sawtimber is evidence by increasing real prices for ash, oak, and cherry (Kingsley and DeBald 1986). Even species such as yellow-poplar or sugar maple that show no real price gains exhibit significant price differentials by log size and quality (Ohio Agr. Stat. Serv. 1987). Hardwood sawmills also report added haul costs of as much as $100/mbf resulting from the greater haul distances required to obtain adequate supplies of grade 1 and 2 sawlogs (Kronrad 1986).

To increase production of high-quality sawtimber, periodic thinning and improvement cutting is needed to maintain stocking at levels associated with maximum board-foot volume growth, and to concentrate growth on the most desirable trees. Results from thinning studies in upland oak stands show improved sawtimber yields and reduced time to grow large-diameter trees (Gingrich 1971). Although definitive results are not available regarding impacts of thinning on tree quality, Herrick and Morse (1968) project a twofold-to-threefold increase in the proportion of grade 1 butt logs resulting from intensive management of Appalachian hardwood stands.

Whereas viable opportunities exist for investing in hardwood management (Risbrudt and Pitcher 1986), nonindustrial private forest-land owners are reluctant to make these investments. These owners control 70 percent of the Nations' hardwood growing stock (USDA Forest Service 1982). Ownership surveys in Ohio and West Virginia (Birch 1982, Birch and Kingsley 1978) indicate that timber production is seldom the primary reason for owning timberland, yet owners of two-thirds of the nonindustrial private forest land plan to harvest timber. These owners also rank timber prices and the need for money well above cultural treatments as reasons for harvesting timber. Accordingly, commercial thinning may afford the best opportunity for improved hardwood management. Commercial thinning requires no investment, provides the required immediate cash flow, and provides periodic cash flows to bolster economic returns and continued interest in forest management.

Opportunities for commercial thinning are constrained by harvest revenue that must exceed harvesting costs. Product mix and available markets, factors that affect thinning revenues, are the focus of this paper. Harvesting cost for alternative logging technologies is the focus of another paper in this same proceedings volume (LeDoux and Baumgras 1989).

## PRODUCT MIX

Revenue from thinning is a function of product mix and product markets. Product mix can be defined as the volume of wood available in alternative primary products. These volumes are affected by tree size, species, quality, and total volume harvested. Species and quality require site-specific assessments. However, evaluating product mix as a function of tree diameter can demonstrate very important trends in thinning revenue.

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The four types of primary products included in this analysis include only bolewood $\geq$ 4.0 inches diameter outside bark (dob) from trees $\geq$ 5.0 inches diameter at breast height (dbh). Product definitions and specifications include:

Large Sawlogs: USDA Forest Service factory grade 3 or better, scaling diameter $\geq$ 10 inches.

Small Sawlogs: USDA Forest Service factory grade 3 or better, 10 inches > scaling diameter $\geq$ 8 inches.

Sawbolts: Sawable roundwood > 6.0 inches dob, suitable for manufacturing wooden pallets or other low-quality sawn products. Because of size and/or quality, will not make a factory grade 3 sawlog.

Pulpwood-fuelwood: Bolewood $\geq$ 4.0 inches dob that will not make sawlogs or sawbolts due to crook, sweep, defect, or diameter constraints.

Total merchantable volume and volume by product type shown in figure 1 represent results from the analysis of 1,770 trees cut from 113 sample thinning plots in overstocked poletimber and small-sawtimber stands of Appalachian hardwood. These even-aged 50- to 70-year-old stands included upland oaks, cove hardwoods, and northern hardwoods growing on medium to good hardwood sites. These stands were thinned from below, removing dominant or codominant trees only if they were of poor quality, or to attain the desired spacing (Baumgras 1984).

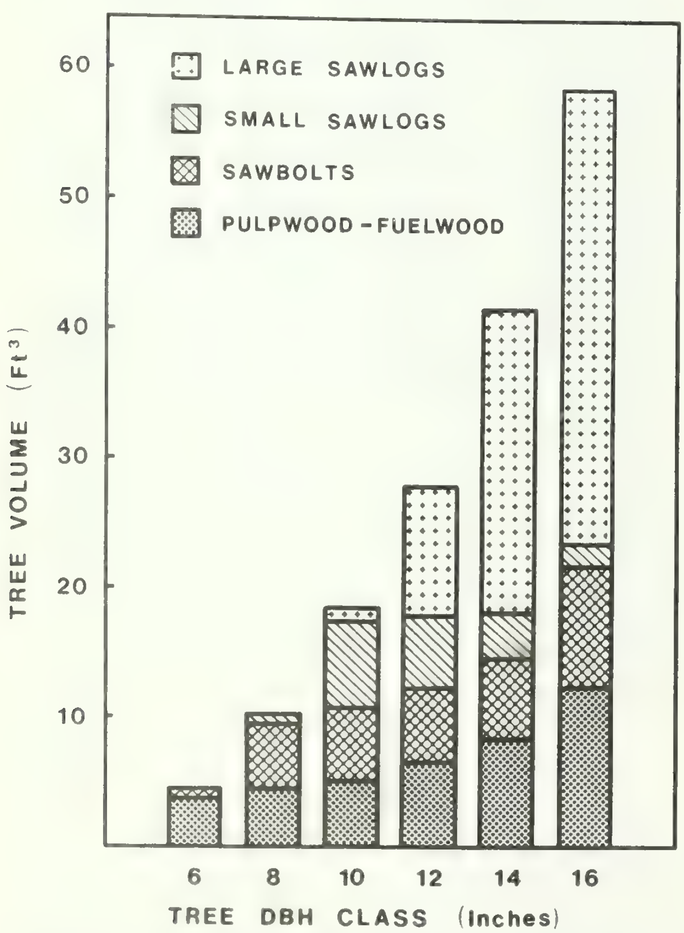


Figure 1.--Average total merchantable volume and product volume per tree by tree dbh class.

The most significant product mix trend is the increase in large-sawlog volume with increasing tree dbh class; from zero at 8 inches to 35 cubic feet at 16 inches dbh (fig. 1). For trees in the smaller dbh classes most likely to be removed in thinning, large sawlogs are not the major component. Small sawlogs and sawbolts represent 40 to 70 percent of the merchantable volume in the 8- to 12-inch dbh classes. This roundwood is often marketed as pulpwood or fuelwood. If markets are available for small sawlogs and sawbolts, these products afford an opportunity to upgrade the product mix and increase thinning revenue throughout the diameter classes shown in figure 1.

## PRODUCT MARKETS AND MULTIPRODUCT HARVESTING

The array of products available and the need to increase thinning revenue identifies a very important role for multiproduct harvesting. Blinn and others (1983) reported a 25 percent gain in delivered product prices from multiproduct harvesting versus pulpwood-only harvests in Lake States hardwoods. Upgrading roundwood values through multiproduct harvesting could prove essential to intensive hardwood management and the required commercial thinnings.

To demonstrate the impact of multiproduct harvesting on thinning revenue, the APTHIN computer program (Baumgras and Yandle 1986) was used to obtain revenue estimates for three product marketing alternatives. The APTHIN program utilizes product volume and weight equations (Baumgras 1984, 1988) to estimate product yields and revenue for thinnings in Appalachian hardwoods. Inputs include the basal area removed by tree dbh classes and product prices. To show thinning revenue as a function of the mean diameter of merchantable trees removed, the required basal area removals were obtained by sorting the data from 113 sample thinning-plots according to the average dbh of trees $\geq$ 5.0 inches dbh removed from each plot. These same plots were used to develop the results shown in figure 1 and to develop the yield equations incorporated in APTHIN. For this application, the sample plot data are used only to define the relationship between average diameter of merchantable trees and basal area removed by tree dbh class.

The product prices included in this analysis represent a range of prices surveyed from published hardwood forest products price bulletins (Engalichev 1985, Ohio Agr. Stat. Serv. 1987, Univ. Wisc. 1986).

Input prices by product classification and relative price level are:

| | | High | Medium | Low |
|---|---|---|---|---|
| Large sawlogs | \$/Mbf[a] | 175 | 150 | 120 |
| Small sawlogs | \$/Mbf | 120 | 105 | 90 |
| Sawbolts | \$/Mbf | 115 | 100 | 85 |
| Pulpwood | \$/100 $ft^3$ | 55 | 44 | 33 |

[a] International 1/4-inch log scale.

The average unit revenue curves in figure 2 contrast three product marketing alternatives; (1) pulpwood only, (2) pulpwood - large sawlogs, and (3) pulpwood - sawbolts - small sawlogs - large sawlogs. To demonstrate maximum revenue gains from multiproduct harvesting, high relative prices are assumed for sawlogs and sawbolts, with low relative prices for pulpwood. The slope of the two multiproduct curves reflects the product price differentials and the product mix that changes with the average dbh of trees harvested. The vertical distance between curves represents revenue gains from product sorting. Gains from large sawlogs exceed those from small sawlogs and sawbolts when cut trees average 8.5 inches dbh or larger. Large sawlog volume and revenue gains, the distance between the sawlog-pulpwood curve and the pulpwood curve, continue to increase with dbh. Revenue gains from sorting large sawlogs range from \$0.01/$ft^3$ at 7 inches, to \$0.27/$ft^3$ at 12 inches. Gains from sawbolts and small sawlogs remain relatively constant at \$0.03/$ft^3$ to \$0.06/$ft^3$ (fig. 2).

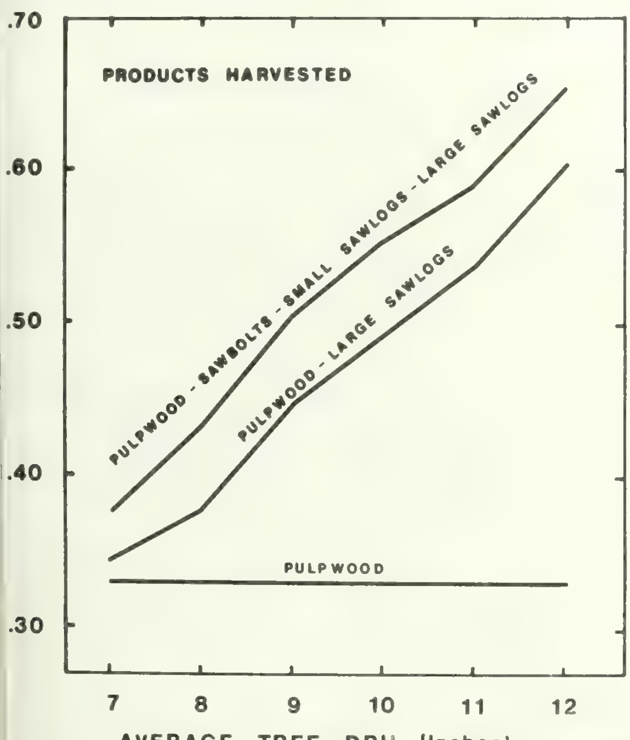


Figure 2.--Average unit revenue by average dbh of trees harvested and products harvested.

At the lower end of the diameter range associated with early thinning, small sawlogs and sawbolts provide a potentially important source of revenue to promote commercial thinning. However, either higher prices for pulpwood, or lower prices for small sawlogs and sawbolts, would diminish gains from sorting those two products. The resulting revenue curve would approach that of the pulpwood-large sawlog mix. Consequently, strong markets for material of the size and quality of sawbolt and small sawlogs would significantly improve prospects for early commercial thinnings. These markets also can provide needed outlets for small roundwood in the absence of pulpwood or fuelwood markets.

## ECONOMIC FEASIBILITY

Evaluating the economic feasibility of commercial thinnings requires estimates of both costs and revenues. The variability of unit costs and revenues and the resulting shifts in feasibility are demonstrated in figure 3. The three stump-to-mill cost curves were developed from the ECOST computer program, and assume chainsaw felling and skidding with a JD-540B rubber-tired skidder (LeDoux 1988). ECOST estimates the stump-to-mill cost of cable or ground-based logging eastern hardwoods. Detailed estimates are available for felling, bucking, yarding or skidding, loading, and hauling. The computer program summarizes results from selected time and motion studies that have been generalized using computer simulation methods.

The slope of the cost curves show changes occurring with increasing tree diameter and harvested volume/acre. The vertical distance between cost curves represents differences in one-way haul distance: 20 miles, 40 miles, and 60 miles. Haul cost assumptions include a tractor-trailer combination averaging 25 miles per hour. Including haul distance and cost enables market location as well as price to enter the feasibility analysis. For the sake of simplicity, it is assumed that all primary products are hauled the same distance.

The three revenue curves assume multiproduct harvesting when product price differentials increase average unit revenue. For simplicity, it is also assumed that all four products are priced at the same relative level: high, medium, or low. Although numerous combinations could exist for product prices and market locations, the upper and lower cost and revenue curves essentially bound these possibilities.

With three levels each for cost and revenue, there are nine possible intersections. Each intersection represents the lower limits of feasibility with respect to the average dbh that can be commercially thinned under the stated assumptions. Under the best case scenario, a short haul with high prices, thinning is feasible at approximately 8.2 inches average dbh (fig. 3).

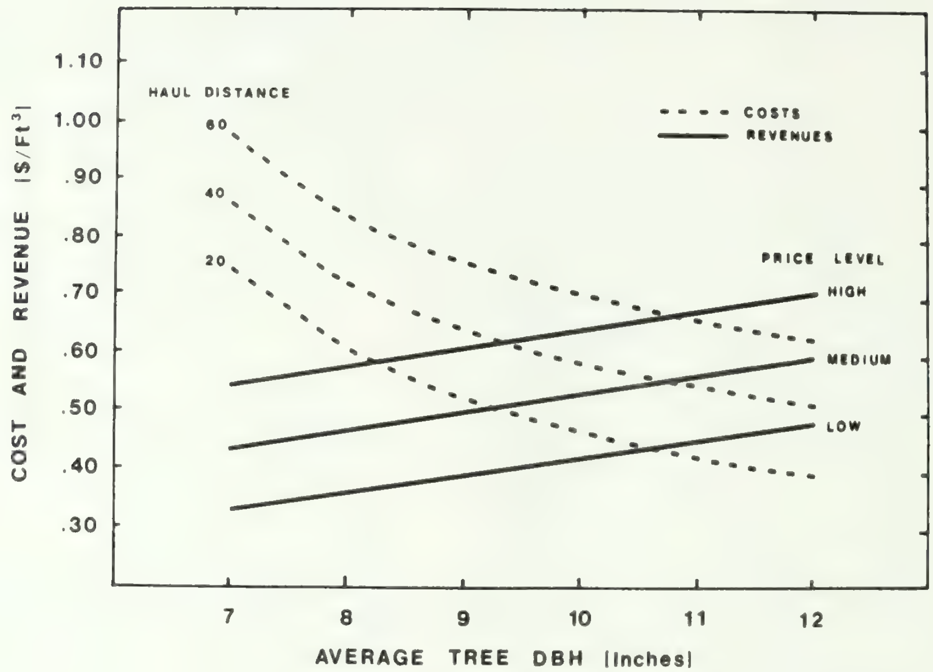


Figure 3.--Simulated cost and revenue per unit by the average dbh of trees harvested, haul distances, and relative price levels.

The minimum average dbh increases to approximately 9.2 inches when prices are reduced to medium levels or haul distance is increased by 20 miles. On the basis of diameter growth results reported for upland oaks by Gingrich (1971), this shift would postpone thinning about 10 years. At 60 miles, both medium- and low-price levels prove infeasible up to 12 inches average dbh.

The impact of price levels and haul distance demonstrates the trade-offs between these two important variables. In this analysis, a shift between relative price levels is roughly equivalent to a shift of 20 miles in haul distance. With smaller trucks or poorer roads, the impact of distance could be much greater. These results indicate that market location and resultant haul distances are as important to commercial thinning as product price levels. Alternative harvesting technology may also reduce stump-to-truck costs and thereby improve prospects for early thinning.

## DISCUSSION

The constraints imposed by forest land ownership and landowner objectives seem to directly link prospects for improved hardwood management to the economic feasibility of commercial thinning. Accordingly, these results should help forest managers and planners recognize the product mix available from hardwood thinning, and to understand the important roles of multiproduct harvesting, product prices, and market locations. These variables affect revenue required to initiate thinning and the timing of commercial thinnings. Also affected are resultant growth and quality response. These variables should therefore be included in the development of forest management plans.

Many forest managers are acutely aware that poor markets often limit opportunities for commercial thinning. Although current markets may not favor commercial thinning, ongoing shifts in hardwood utilization and projected hardwood demand levels are encouraging. Important utilization trends include the increased production of composite wood products such as waferboard, oriented strand board, and medium density fiberboard; products that provide markets for thinning material (Kallio 1986). New processes for manufacturing sawn products from small logs should likewise improve hardwood markets (Reynolds and Kallio 1986). The growing demand for wooden pallets also can be

satisfied with the large volume of small sawlogs and sawbolts available from thinning (Anderson 1987).

Long-term projections also show large increases in the Nation's total demand for hardwood roundwood increasing from 3.0 billion cubic feet in 1976, to 9.6 billion cubic feet in 2030 (USDA For. Serv. 1982). These projections include a threefold increase in pulpwood and fuelwood demand, with much of the pulpwood going to panel and board products. A 1.2-billion-cubic-foot increase is projected for hardwood sawlogs. Appropriately 55 percent of sawlog volume will go into shipping products such as wooden pallets.

To identify opportunities for commercial thinning, forest managers and forest industries must periodically update their feasibility analyses to reflect the ongoing developments in harvesting technology and product markets, as well as tree growth and the resulting changes in timber stand attributes. This process could be automated by using a computer to link forest inventory data bases and growth models with harvesting cost and revenue models such as ECOST (LeDoux 1985, 1988) and APTHIN. The required cost and revenue analyses could then be applied to each candidate stand in the forest inventory file. Resulting output could list economically feasible thinning sites, acres of feasible thinning sites, or product volume available from commercial thinning. Such results would identify marketing and utilization opportunities and help update forest management plans.

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CONTEMPORARY LOGGING TECHNOLOGY FOR HARVESTING YOUNG

CENTRAL HARDWOODS[1]

Chris B. LeDoux[2]
John E. Baumgras

Abstract.--Thinning young central hardwood stands presents an opportunity for increasing the growth and yield of quality sawtimber. Planners, loggers, and managers need to know what types of logging technology are available for treating young stands. In this paper, three types of logging technology applicable to young central hardwoods are presented.

## INTRODUCTION

Commercial harvesting of forest products is a key linkage in managing young central hardwoods. If forest management is to be intensified, managers and planners must become familiar with the types of logging technology available to them. The costs of operating such technology also must be documented and particular attention must be given to how individual site and stand variables impact logging costs. Planners and managers also should understand the impact of individual silvicultural treatments on logging cost. The distance that wood must be transported to landings and then on to sawmills or other processing centers also impacts logging costs and must be accounted for in planning treatments for young stands (LeDoux 1988).

A wide array of harvesting machinery is available for conducting thinning operations in young central hardwoods. These include cable systems, ground-based systems, and portable bunching winches. It is beyond the scope of this paper to deal with all of the available logging systems. In this paper, we present three logging technologies and specific machine types applicable to thinning young central hardwoods. We also demonstrate the impact of select stand attributes such as d.b.h. of trees removed, the total volume removed, and stump-to-landing distance (slope yarding/skidding/winching distance) on logging costs.

## CABLE SYSTEMS

Cable logging systems are generally used to harvest timber on steep, difficult, or environmentally sensitive sites. A wide range of cable machines from small, relatively inexpensive to very large and expensive machines are available (LeDoux 1985, LeDoux 1987). Cable systems generally require more crew training as well as on the ground planning layout to maintain economical production levels. The two cable machines discussed are capable of operating under most young central hardwood site conditions and handling potential volume removals. The Bitterroot[3] is a small, relatively inexpensive machine with a low production rate designed to operate in stands with average tree d.b.h. of 7 to 9 inches (fig. 1). The second machine, the Clearwater Yarder, is a slightly larger machine with higher cost and higher production capable of operating in stands with an average tree d.b.h. of 9 to 12 inches. The costs are projected using ECOST version 2.0 (LeDoux 1988[4]). Although the smaller Bitterroot could operate in larger d.b.h. stands, it is not recommended to do so if production levels, costs, and related stand damge are to remain at an acceptable level.

Stump-to-landing costs decrease with increasing average cut-tree d.b.h. for each volume removal (fig. 1). Total stump-to-landing costs increase with increasing volume removal because we simply have more wood to remove. However, combinations of

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[3]The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

[4]LeDoux, Chris B. 1988. ECOST - Version 2 - Stump-to-mill production cost equations and computer program. Unpubl. report on file at U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, 180 Canfield St., Morgantown, WV. 26505.

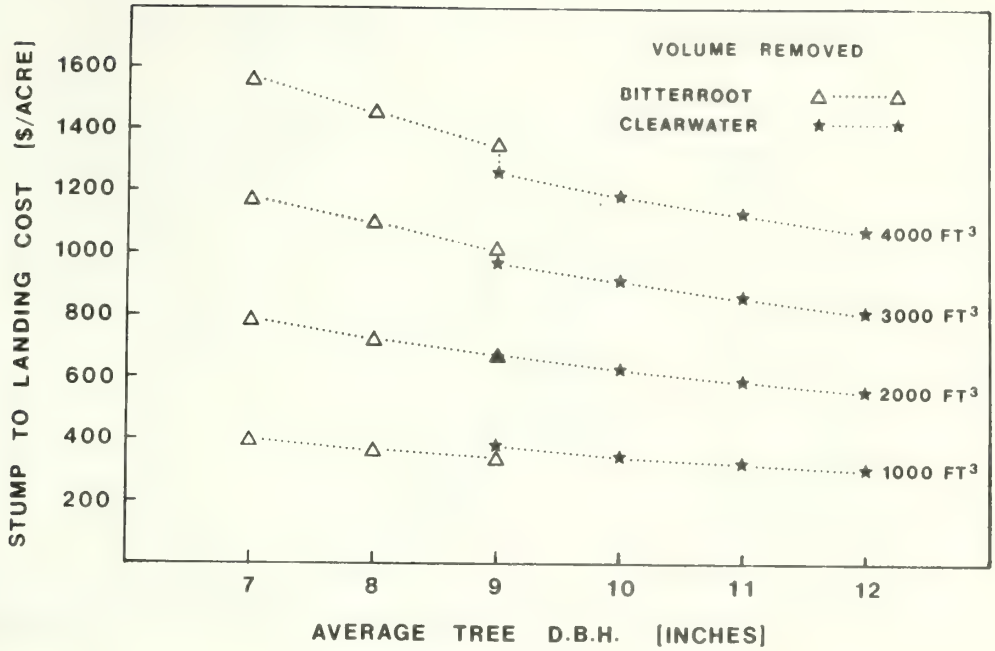


Figure 1.--Simulated stump-to-landing cost for the Bitterroot and Clearwater cable yarders by average cut-tree d.b.h. and volume removed per acre.

high volume removals and large d.b.h. trees are most desirable when all costs (stump-to-mill) are included. The stump-to-landing costs would normally continue to decrease with increasing d.b.h., but we must remember that in this application, we have shifted from a small inexpensive machine to a large expensive yarder for removal of trees larger than 9-inches d.b.h.

## GROUND-BASED SYSTEMS

Ground-based systems are generally used to harvest timber on gentle terrain. A large assortment of machines exist including skidders, forwarders, tractors, and small 4-wheel drive units. The machines can be track or rubber-tired based and can be pulled behind a larger unit or can be self-propelled. A wide range of sizes and related costs and production rates are available to select from. One of the most widely used ground-based systems is the 4-wheel drive rubber-tired skidder with either a grapple or chokers to transport the load. In this paper, we highlight a John Deere 540B rubber-tired skidder with chokers that is capable of operating in most young central hardwood stands.

Skidding costs per unit production decrease with increasing average cut-tree d.b.h. and volume removed (fig. 2). For example, the cost at 1,000 $ft^3$ removal and d.b.h. of 7 inches is $0.32/$ft^3$ and decreases to $0.189 at 12 inches, which is about a 41 percent decrease in cost. This illustrates the added cost of harvesting smaller d.b.h. trees from thinnings. As with cable systems, combinations of heavy volume removals and large cut-tree diameters favored by loggers provide the minimum stump-to-landing costs. Information such as that in figure 2 can be used by planners and managers to better understand the impact of tree size and volume removals on logging cost and stumpage returns.

## PORTABLE WINCHING SYSTEMS

Many times logging machinery is unable to develop full payloads when operating in young stands where the average piece size is small. This generally occurs in young thinnings because the pieces are small and scattered, making development of a full payload difficult if not impossible. A partial solution to this challenge is to use portable and fixed bunching winches to bunch the pieces along the extraction path allowing the larger, more expensive yarder, skidder, or forwarder to develop a full payload taking best advantage of its capability. Bunching winches are

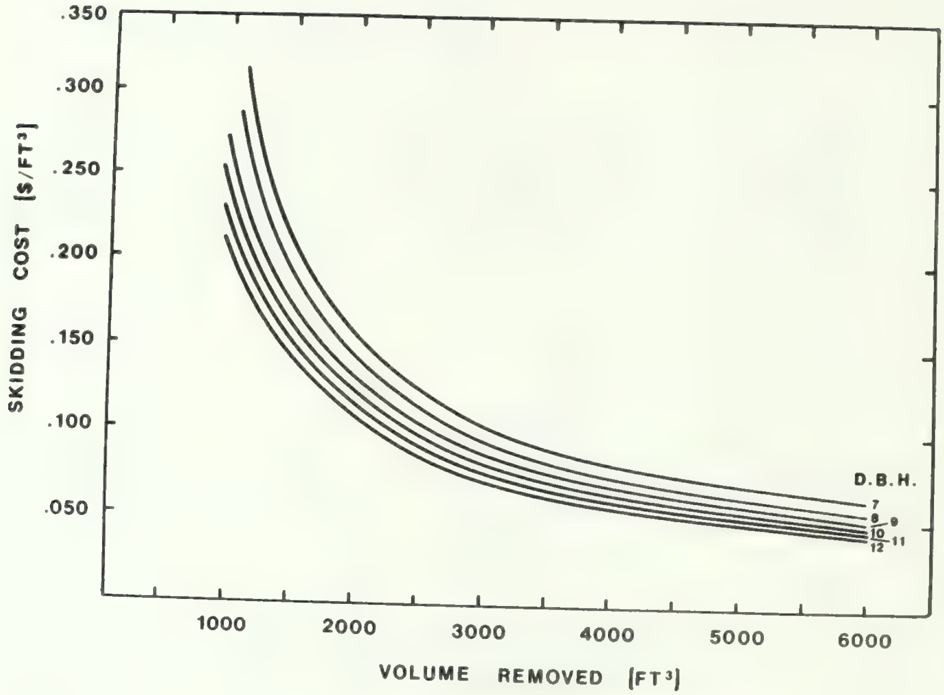


Figure 2.--Simulated skidding cost for the John Deere 540B skidder by volume removed per acre and average cut-tree d.b.h.

generally cheaper to own and operate than conventional skidders or cable yarders. Many types of winches are available to select from. In this article, we highlight the Radio Horse 9 Winch (LeDoux et al. 1987).

The impact of average cut-tree d.b.h. and volume removal on bunching cost for the Radio Horse 9 is shown in figure 3. The bunching costs range from a high of $0.313/ft$^3$ at d.b.h. of 4 inches and volume removal of 500 ft$^3$/acre to low of $0.024/ft$^3$ at 12 inches d.b.h. and volume removal of 700 ft$^3$/acre. The impact of average cut-tree d.b.h. on bunching cost is shown in the following example. The bunching cost at 4 inches d.b.h. and 500 ft$^3$ removal is $0.313/ft$^3$, and decreases to $0.036/ft$^3$ at 12 inches d.b.h., which is an 88 percent decrease for the same volume removal. Again, as for the previous systems, operating in small d.b.h. stands with low volume removals makes harvesting marginal.

## SLOPE YARDING DISTANCE

Stump-to-landing distance will significantly affect productivity and costs. Figure 4 shows the impact of distance on the costs of bunching, skidding, and yarding. Generally, for all logging systems, removal costs rise with increasing distance. Although comparisons among machines based on slope yarding distance alone are difficult and could be misleading, we show the relative affect of slope yarding distance on the systems mentioned previously. One would not expect cable systems in hardwood applications to reach farther than about 900 feet, ground-based systems about 1/3 mile, and bunching winches about 150 feet. Obviously, these systems could reach farther on select applications resulting in excessively high removal costs.

For example, the cost of using the Bitterroot yarder at a slope yarding distance of 350 feet is $0.159/ft$^3$ increasing to $0.228/ft$^3$ at a distance of 750 feet, which is an increase of about 43 percent. Careful attention to logging unit layout,

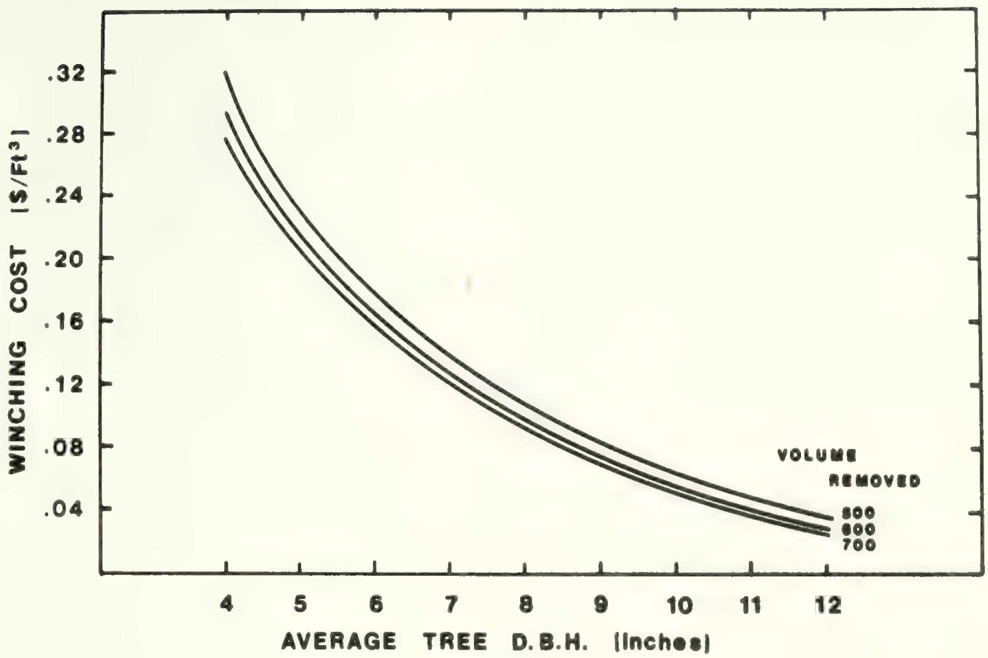


Figure 3.--Simulated winching cost for the Radio Horse 9 prebunching winch by average cut-tree d.b.h. and volume removed per acre.

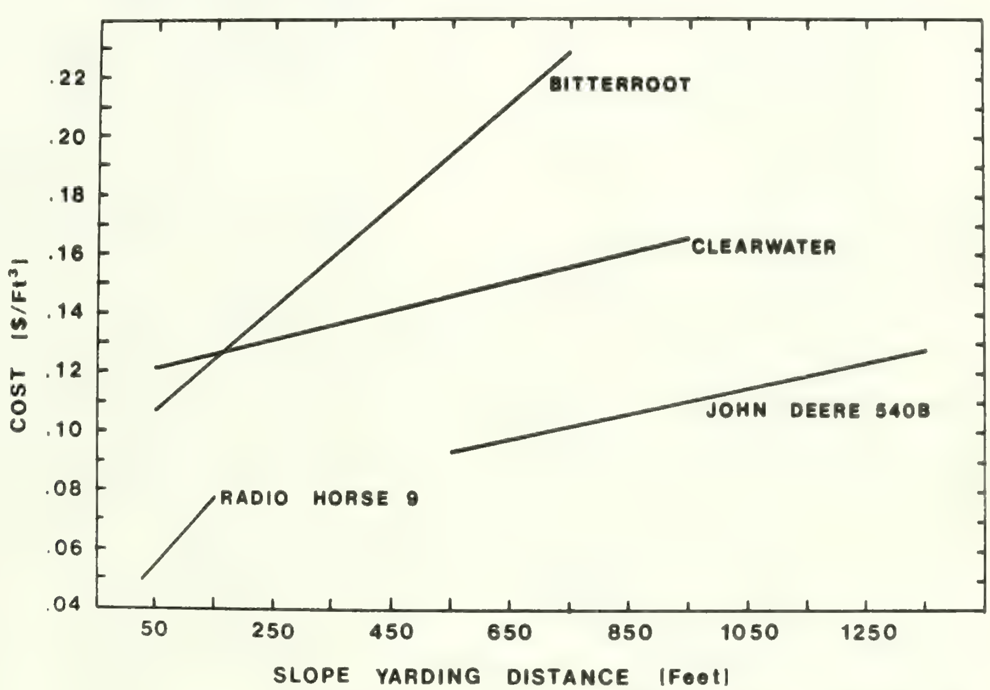


Figure 4.--Simulated yarding/skidding/winch costs for the Bitterroot and Clearwater yarders, the John Deere 540B skidder, and the Radio Horse 9 bunching winch by slope yarding distance. Conditions: average cut d.b.h., 9 inches for all systems; volume removed per acre, 700 $ft^3$/acre for the Radio Horse 9, 3,000 $ft^3$/acre for all other systems.

road and landing location, and piece size constraints can help keep removal costs within economical bounds (LeDoux 1984, Baumgras 1987).

## LOGGING SYSTEM COMPARISON

The type of logging technology selected for removing young hardwood logs can undoubtedly affect the production rate and cost of that effort. Figure 5 shows the relative cost difference of wood removal using the three harvesting technologies described in this paper. In all situations, removal costs decrease with increasing average cut-tree d.b.h. The Radio Horse 9 winch is competitive with the John Deer 540B skidder in the 7 to 8 inch d.b.h. range. Otherwise, the Radio Horse 9 winch is the most economical to operate, followed by the John Deere 540B skidder, and next the more expensive cable systems, the Bitterroot and Clearwater yarders.

For example, at an average cut-tree d.b.h. of 9 inches, the Radio Horse 9 cost is $\$0.067/ft^3$ which is about 26 percent less expensive than the John Deere 540B cost of $\$0.091/ft^3$, which is about 55 percent less than the Bitterroot yarder cost of $\$0.150/ft^3$. The John Deere 540B cost at average cut-tree d.b.h. of 7 inches is $\$0.113/ft^3$, which is about 35 percent less than the Bitterroot yarder cost of $\$0.175/ft^3$. These relative cost differences can be used as estimates of environmental protection cost. Clearly, to harvest timber on steep, difficult, environmentally sensitive sites will cost more as more expensive logging technology is used. Comparisons such as those shown in Figure 5 allow the managers and planners to visualize the cost differences of using alternative logging technologies.

## CONSIDERATIONS FOR MANAGERS

Simulations presented here show the difference in cost of alternative logging technologies. Before deciding to log an area, the managers and planners must consider the interaction of logging equipment and site and stand specific variables such as average cut d.b.h., volume removed, and slope yarding distances required. Also considered should be

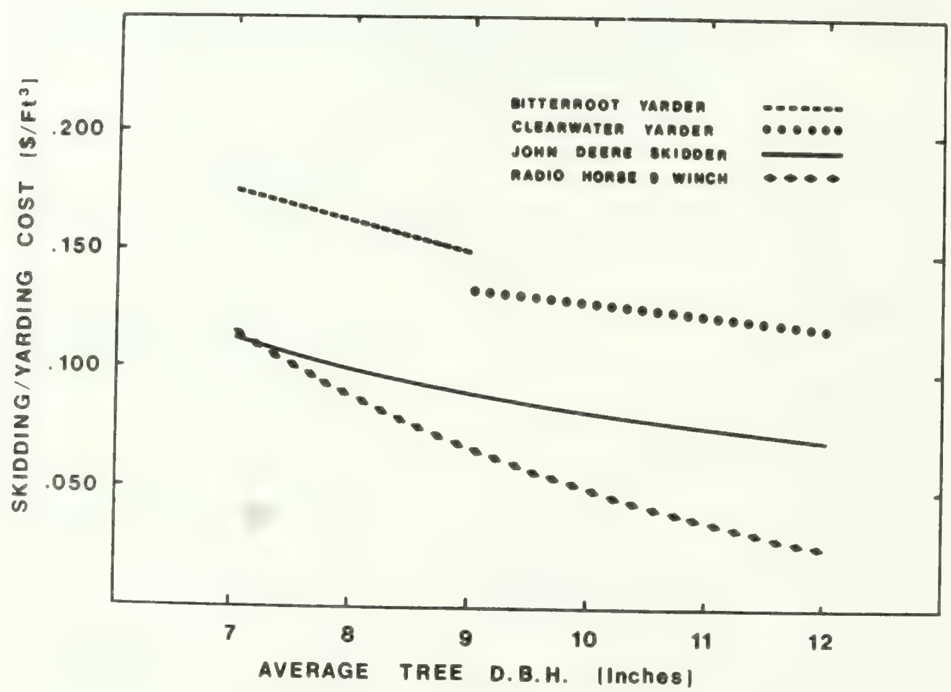


Figure 5.--Simulated comparative yarding/skidding/winching costs for the Bitterroot and Clearwater yarders, the John Deere 540B skidder, and the Radio Horse 9 bunching winch by average cut-tree d.b.h. Conditions: slope yarding distance, 300 feet for the Bitterroot and Clearwater, 100 feet for the Radio Horse 9, 500 feet for the John Deere 540B; volume removed, 3,000 $ft^3$/acre for the Bitterroot, Clearwater and John Deere 540B, 700 $ft^3$/acre for the Radio Horse 9.

primary product markets and the product mix available from the trees to be harvested, the topic of a companion paper in this same proceedings (Baumgras and LeDoux 1988). The logging manager also should be aware of other logging technologies and their comparative costs.

The simulated results summarized in figures 1 to 5 span the range of potential forest harvest site conditions. Clearly, for many applications, particularly in thinning young stands some of the combinations of average cut-tree diameter and volume removed shown in the above figures will not exist. The results however, do show the relative shifts in logging costs due to such volume cut and average tree size diameter combinations.

Simulations such as those presented here do not provide all the answers on which equipment to select or how to apply it. However, these methods illustrate the different types of harvesting technology available to thin young central hardwoods and help pinpoint the variables involved and their interaction so that loggers, planners, and managers can choose the best systems for treating young hardwood stands or final harvest operations.

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VERIFICATION OF TREE GRADING ALGORITHMS
WITH A HYPOTHETICAL HARDWOOD FOREST[1]

C. J. Liu, Jeffrey W. Stringer, and D. J. McLaren[2]

Abstract.--Standing tree grades in a hypothetical hardwood forest were obtained from execution of a newly designed tree grading algorithm, using computer simulated grading characteristics. For a hypothetical population of 500 trees, tree characteristics generated included diameter at breast height, diameter inside bark at the top of the grading section, Girard form quotient, number and lengths of clear cuttings, and percent cull due to sweep, crook and rot. These characteristics were inputs for a tree grading model consisting of a forester as hardware and the tree grading algorithm as software. Mental execution of the tree grading algorithm by the forester produced tree grade as output from the tree grading model. The purpose of this paper was to establish the correctness and to evaluate the efficiency of the tree grading algorithm that permits systematic classification of standing tree grade without using a computer in woods.

## INTRODUCTION

Determining hardwood tree grades is not an amicable task for most beginning tree graders. Hanks (1976) and Miller et al. (1986) have devised methods to assist in learning the USDA Forest Service hardwood tree grading system. More recently, two tree grading algorithms-the general tree grading algorithm (TGA) and the form class tree grading algorithm (FCTGA)-were developed (Liu and McLaren 1987, Liu 1988) for determining hardwood tree grades. This paper presents grading characteristics of a hypothetical 500-tree population that was simulated for the verification of these tree grading algorithms.

### Tree Grading Algorithms

Application of TGA for tree grade determination can be illustrated by visualizing a tree grading model (TGM) comprising a forester, acting like a piece of hardward, and the TGA, the software that prescribes activities constituting tree grading processes (fig. 1).

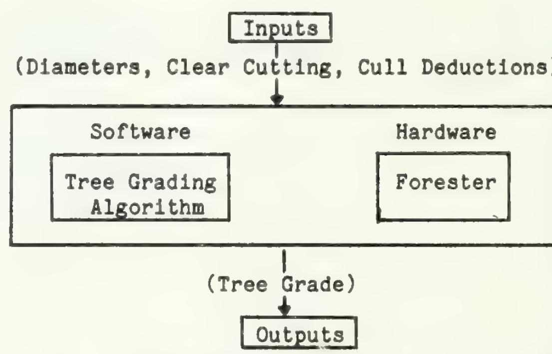


Figure 1.--Schematic representation of a tree grading model.

The TGA (fig. 2) is a set of logically arranged statements representing conditions required by the USDA Forest Service hardwood tree grade system. Tree characteristics such as stem diameter, number and lengths of clear-cuttings, and amount of cull deductions are used as input to the model. The forester executes the TGA by evaluating a statement and determining if it is true or false, based on the input data. The forester branches to another statement according to the sequence of control built in the TGA. The forester repeats this evaluation-branching activity until the output, the tree grade, is obtained. TGA systematizes tree grading by making it a methodical procedure that can be carried out easily and quickly by a forester without computer-related training and experience. FCTGA (fig. 3) is very similar to TGA except that it is used with a predetermined form class.

[1]To be read at the 7th Central Hardwood Forest Conference, Carbondale, Illinois, March 5-8, 1989. The investigation reported in this paper (88-8-63) is in connection with a project of the Kentucky Agricultural Experiment Station and is published with the approval of the director.

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General Tree Grading Algorithm (TGA)[‡]

| | Yes/No |
|---|---|
| 1. DBH ≥ 15.6" (14.6" for basswood & ash) | 4/2 |
| 2. DBH ≥ 12.6" | 7/3 |
| 3. DBH ≥ 9.6" | 10/BG |
| 4. DIT ≥ 19.6" | 11/5 |
| 5. DIT ≥ 15.6" | 12/6 |
| 6. DIT ≥ 12.6" (11.6" for basswood & ash) | 13/7 |
| 7. DIT ≥ 11.6" | 16/8 |
| 8. DIT ≥ 10.6" | 17/9 |
| 9. DIT ≥ 9.6" | 18/10 |
| 10. DIT ≥ 7.6" | 19/BG |
| 11. SCC ≥ $10'_{12}$ $11'8"_{14}$ $13'4"_{16}$ in 1 or 2 CC—each CC ≥ 3′ | 20/14 |
| 12. SCC ≥ $10'_{12}$ $11'8"_{14}$ $13'4"_{16}$ in 1 or 2 CC—each CC ≥ 5′ | 20/14 |
| 13. SCC ≥ $10'_{12}$ $11'8"_{14}$ $13'4"_{16}$ in 1 or 2 CC—each CC ≥ 7′ | 20/14 |
| 14. SCC ≥ $8'_{12}$ $9'4"_{14}$ $10'8"_{16}$ in 1, 2 or 3 CC—each CC ≥ 3′ | 15/19 |
| 15. TCD ≤ 9% or [9% < ROT ≤ 40% and (no S&C nor SDF)] | G2/23 |
| 16. SCC ≥ $8'_{12}$ $9'4"_{14}$ $10'8"_{16}$ in 1, 2 or 2 CC—each CC ≥ 3′ | 22/19 |
| 17. SCC ≥ $8'_{12}$ $9'4"_{14}$ $10'8"_{16}$ in 1 or 2 CC—each CC ≥ 3′ | 22/19 |
| 18. SCC ≥ $10'_{12}$ $11'8"_{14}$ $13'4"_{16}$ in 1 or 2 CC—each CC ≥ 7′ | 22/19 |
| 19. SCC ≥ $6'_{12}$ $7'_{14}$ $8'_{16}$—all CC ≥ 2′ | 23/BG |
| 20. TCD ≤ 9% | G1/21 |
| 21. S&C ≤ 15% and TCD ≤ 40% | G2/23 |
| 22. TCD ≤ 9% | G2/23 |
| 23. TCD ≤ 50% | G3/BG |

[‡]Numerical subscripts represent lengths (ft) of grading sections. Symbols used in the table stand for: DBH—diameter outside bark at breast height; DIT—Diameter inside bark at top of grading section; CC—clear cutting(s); SCC—sum of the longest 1, 2, or 3 clear cuttings that are equal to or longer than the specified length of CC; TCD—total cull deduction (sweep, crook, & rot); S&C—cull deduction due to sweep and/or crook; SDF—surface defect(s) on grading face; G1—grade 1; G2—grade 2; G3—grade 3; and BG—below grade.

Figure 2.--General Tree Grading Algorithm (TGA).

Form Class (80) Tree Grading Algorithm.†

| | | Yes/No |
|---|---|---|
| 1. | DBH $\geq 22.69''^{12}\ 23.11''^{13}\ 23.56''^{14}\ 24.02''^{15}\ 24.50''^{16}$ | 8/2 |
| 2. | DBH $\geq 18.06''^{12}\ 18.40''^{13}\ 18.75''^{14}\ 19.12''^{15}\ 19.50''^{16}$ | 9/3 |
| 3. | DBH $\geq 15.60''^{12}\ 15.60''^{13}\ 15.60''^{14}\ 15.60''^{15}\ 15.75''^{16}$ | 10/4 |
| ‡ | DBH $\geq 13.43''^{12}\ 13.68''^{13}\ 13.94''^{14}\ 14.22''^{15}\ 14.50''^{16}$ | 10/4 |
| 4. | DBH $\geq 13.43''^{12}\ 13.68''^{13}\ 13.94''^{14}\ 14.22''^{15}\ 14.50''^{16}$ | 13/5 |
| 5. | DBH $\geq 12.60''^{12}\ 12.60''^{13}\ 12.74''^{14}\ 12.99''^{15}\ 13.25''^{16}$ | 14/6 |
| 6. | DBH $\geq 12.60''^{12}\ 12.60''^{13}\ 12.60''^{14}\ 12.60''^{15}\ 12.60''^{16}$ | 15/7 |
| 7. | DBH $\geq 9.60''^{12}\ 9.60''^{13}\ 9.60''^{14}\ 9.60''^{15}\ 9.60''^{16}$ | 16/BG |
| 8. | SCC $\geq 10'_{12}\ 11'8''_{14}\ 13'4''_{16}$ in 1 or 2 CC-each CC $\geq 3'$ | 17/11 |
| 9. | SCC $\geq 10'_{12}\ 11'8''_{14}\ 13'4''_{16}$ in 1 or 2 CC-each CC $\geq 5'$ | 17/11 |
| 10. | SCC $\geq 10'_{12}\ 11'8''_{14}\ 13'4''_{16}$ in 1 or 2 CC-each CC $\geq 7'$ | 17/11 |
| 11. | SCC $\geq 8'_{12}\ 9'4''_{14}\ 10'8''_{16}$ in 1, 2 or 3 CC-each CC $\geq 3'$ | 12/16 |
| 12. | TCD $\leq$ 9% or [9% < ROT $\leq$ 40% and (no S&C nor SDF)] | G2/20 |
| 13. | SCC $\geq 8'_{12}\ 9'4''_{14}\ 10'8''_{16}$ in 1, 2 or 3 CC-each CC $\geq 3'$ | 19/16 |
| 14. | SCC $\geq 8'_{12}\ 9'4''_{14}\ 10'8''_{16}$ in 1 or 2 CC-each CC $\geq 3'$ | 19/16 |
| 15. | SCC $\geq 10'_{12}\ 11'8''_{14}\ 13'4''_{16}$ in 1 or 2 CC-each CC $\geq 7'$ | 19/16 |
| 16. | SCC $\geq 6'_{12}\ 7'_{14}\ 8'_{16}$-all CC $\geq 2'$ | 20/BG |
| 17. | TCD $\leq$ 9% | G1/18 |
| 18. | S&C $\leq$ 15% and TCD $\leq$ 40% | G2/20 |
| 19. | TCD $\leq$ 9% | G2/20 |
| 20. | TCD $\leq$ 50% | G3/BG |

†Numerical superscripts represent heights at the top of grading sections while numerical subscripts represent lengths of grading sections. Symbols used stand for: DBH—diameter outside bark at breast height; DIT—diameter inside bark at top of the grading section; CC—clear cuttings(s); SCC—sum of clear cuttings; TCD—total cull deduction (sweep, crook, & rot); S&C—cull deduction due to sweep and/or crook; SDF—surface defect(s) on grading face; G1—grade 1; G2—grade 2; G3—grade 3; BG—below grade.

‡For basswood and ash only.

Figure 3.--Form Class (80) Tree Grading Algorithm.

## Distributions of Tree Characteristics

To establish the correctness and to evaluate the efficiency of the TGA, the procedure just described was repeated by grading 500 trees in a hypothetical hardwood forest. Grading characteristics of the 500 trees were computer generated by hypothesizing their distributions. For example, dbh distribution was assumed to be inverse J-shaped and the distribution of Girard form quotient was programmed to reproduce that of the sum of form-class averages of all species in table 4 of the pamphlet "Tables For Estimating Board-Foot Volume of Timber" (Mesavage and Girard 1946). Lacking any information about the number and lengths of clear-cuttings, the distribution of clear-cuttings was purely imaginary.

Distributions of grade characteristics are shown in figure 4. All 500 trees in the population have dbh's from 10 to 34 inches (fig. 4-a). Generated distributions of sweep (fig. 4-b), crook (fig. 4-c), and rot (fig. 4-d) are continuous ones with a maximum amount of 25%, 25%, and 50%, respectively. For presentation purposes, these data are aggregated into either 4 or 5 groups with division lines drawn to match limitations set forth by the grading rules. For any tree, the Girard form quotient falls between .746 and .835 (fig. 4-e). As can be seen in fig. 4-f, number of clear-cuttings progressively decreases as the length of clear-cuttings increases.

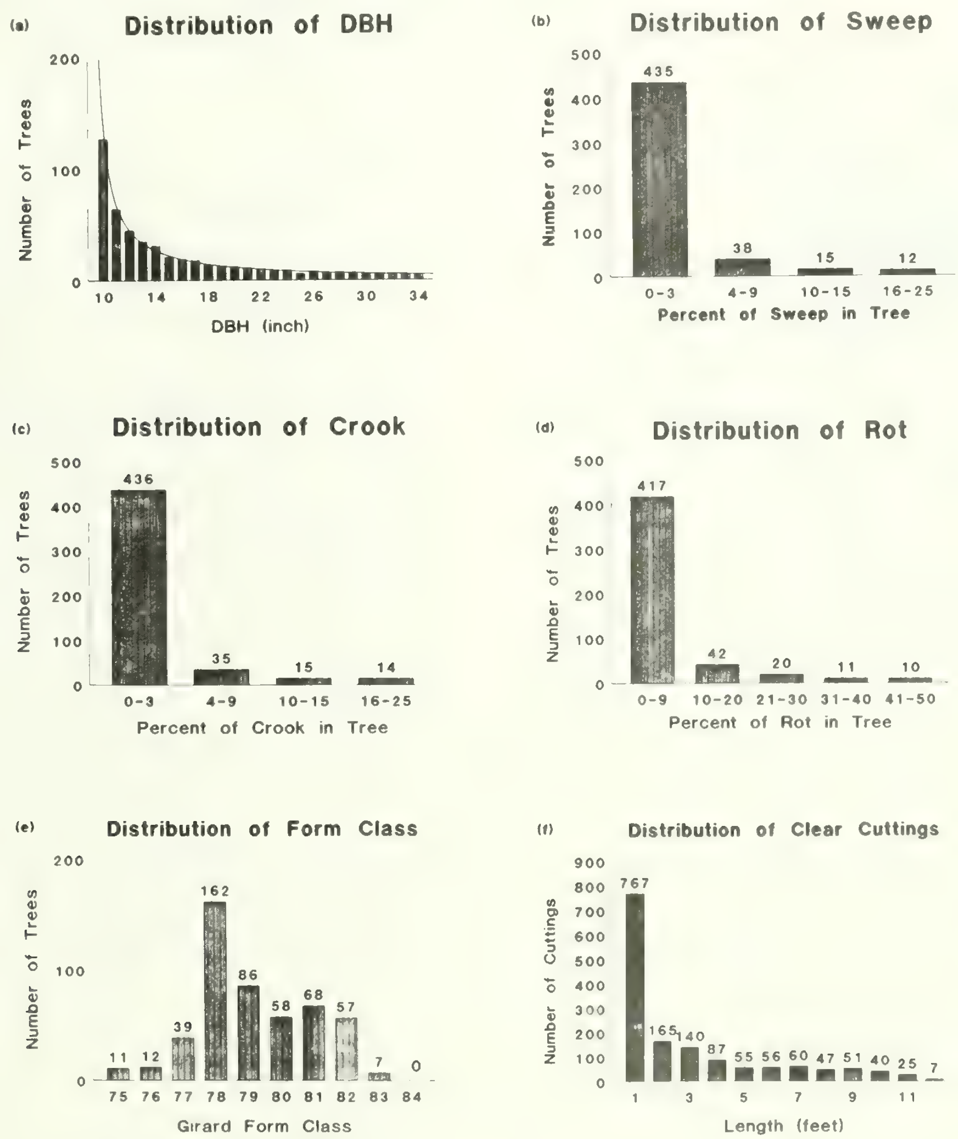


Figure 4.--Distribution of tree characteristics in a computer simulated hypothetical hardwood forest: (a) dbh, (b) sweep, (c) crook, (d) rot, (e) form class, and (f) clear cuttings.

Tree Grades in the Hypothetic Population

Tree grades obtained from 500 simulation runs of the TGM are presented in figure 5. There are, respectively, 18, 82, and 273 trees classified as grade 1, grade 2, and grade 3, while 127 trees were below grade. Note that the distribution of tree grades in this hypothetical population represents a combination of distributions of all grade characteristics considered.

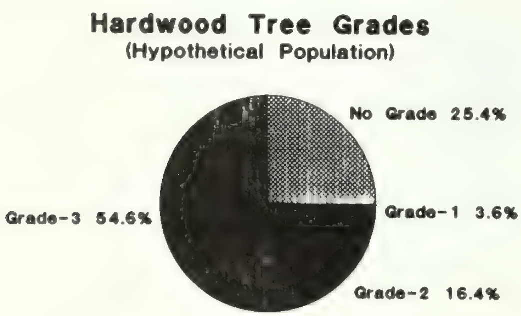


Figure 5.--Grade distribution in a computer simulated hypothetical hardwood forest.

For each and every tree in the population, the computer generated grade was verified by checking the grade obtained from the USDA Forest Service Hardwood Tree Grade for Factory Lumber (Hanks 1976) and was found to be correct. The average number of steps needed to obtain a tree grade using TGA is approximately 6.

DISCUSSION

Tree grading algorithms logically place grade factors involved in a grading system in a set of sequentially arranged branching statements; they not only systematize tree grade procedures but also promote understanding of grading rules. Although these algorithms are devised for grading hardwood trees for factory lumber, the algorithmic methodology used can be readily transferred into other areas of forest management, especially decision-making processes under field conditions.

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# CURRENT TRENDS IN REGIONAL HARDWOOD LUMBER PRODUCTION AND TIMBER USAGE[1]

William G. Luppold and Gilbert P. Dempsey[2]

Abstract.--Hardwood lumber is one of the most important products obtained from our eastern forests. Production of hardwood lumber is increasing with important shifts in output among producing regions. Comparative U.S. and alternative lumber production data are presented, regional shifts noted, and their impact on long-term timber availability discussed.

## INTRODUCTION

In recent years, the demand for many solid hardwood products has increased dramatically. Between 1980 and 1986, exports increased by 40 percent, while the production of wood pallets, furniture, and flooring increased by 44, 5, and 86 percent, respectively (U.S. Dep. Comm., Bur. Cens. 1981-87; U.S. Dep. Cens., International Trade Administration 1988; National Wooden Pallet and Container Association 1987; and National Oak Flooring Manufacturers Association 1980-87). Increased demand caused inflation-adjusted hardwood lumber prices to move higher by 10 percent between 1980 and 1986 (U.S. Dep. Labor, Bur. Labor Stat. 1987). Such changes in demand and price ultimately cause hardwood lumber production to increase and may stimulate changes in comparative economic advantage among producing regions.

Although it may be a foregone conclusion that hardwood lumber production has dramatically increased, information released in the Current Industrial Reports (U.S. Dep. Comm., Bur. Cens. 1957-87) indicated only a 4 percent or 285 million board-foot increase between 1980 and 1986.[3] Such an increase is probably one-fifth the amount of the additional hardwood lumber used by the pallet industry, alone, during this period.

The thesis that underreporting of the increase in hardwood lumber production occurred between 1980 and 1986 is consistent with Cardellichio and Binkley's (1984) finding that hardwood lumber consumption was significantly greater than reported production during this period. Because of the differences in reported and apparent hardwood lumber production, Luppold and Dempsey (in press) developed an alternative series of hardwood lumber production statistics. This series is compared to the Current Industrial Reports (CIR) and Cardellichio and Binkley's findings in figure 1.

This paper is divided into three parts. The first part recaps the procedure used to develop the Luppold-Dempsey hardwood lumber production estimates. These statistics are then used to analyze absolute growth and regional shifts in hardwood lumber production. The last section presents reasons for the changes in hardwood lumber production and the potential impact of current market trends on long-term timber availability.

## ALTERNATIVE PRODUCTION NUMBERS

An alternative hardwood lumber production series was developed through a comparative analysis of state production data reported in the CIR and state production figures reported by alternative sources. The most complete source of alternative production data was the timber product output studies compiled periodically by state forestry officials in cooperation with USDA Forest Service forest resource survey units. These studies report volume of sawlogs destined for and/or received by sawmills. The time intervals for these assessments ranged from annually in some states to every 10 years in other states.

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[1]Paper presented at the Seventh Central Hardwood Forest Conference, Carbondale, Ill., March 5-8, 1989.

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[3]Between 1980 and 1986, annual pallet production increased more than 114 million units (National Wooden Pallet and Container Association 1987). If we use a conservative assumption that the average pallet contained 12 board feet of hardwood lumber, this expansion in pallet production represented an increased annual consumption of nearly 1.4 billion board feet of hardwood lumber.

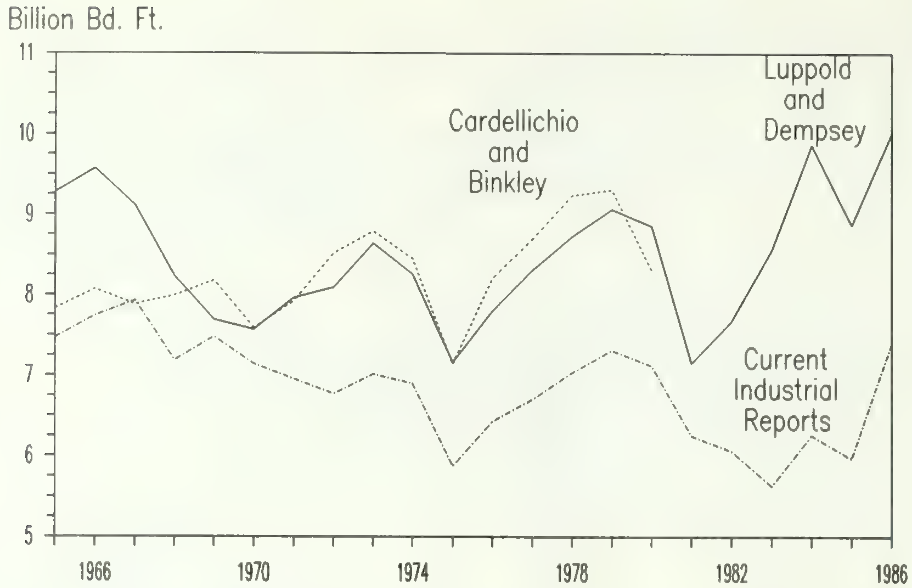


Figure 1.--Comparison of Current Industrial Reports hardwood lumber production volumes to Cardellichio and Binkley usage volumes and Luppold and Dempsey production volumes.

Timber product output data were supplemented with information collected from state lumber production reports, state tax records, and the Tennessee Valley Authority industry surveys.

Because comparative data for every state and year were unavailable, it was necessary to develop annual lumber production multipliers based on the differences between the CIR and alternative-source data for each year. The multiplier developed for a particular year could be used to adjust CIR reported production numbers for which there was no comparable match. Details of this procedure are presented in Appendix A, while results are reported in Appendix, table 2.

After the development of this data, a large regional shift in the volume of hardwood lumber produced from south to north was noted. Regional multipliers were then developed but not reported because of the lack of observations for specific regions for some years. However, the regional multipliers indicated an even more pronounced shift in lumber production from the southern to the northern regions.

## REGIONAL SHIFTS IN HARDWOOD LUMBER PRODUCTION

Examination of table 1 indicates hardwood lumber production grew in the mid-1980's, but was fairly high in the mid-1960's. However, between the years 1965 and 1986 there was a major shift in hardwood lumber production from southern to northern regions. During this period, total U.S. hardwood lumber output increased by 8 percent, while production for the southeast region increased less than 4 percent and output in the south-central region decreased by 18 percent. By contrast, hardwood lumber production in the northeastern and north-central regions increased by 26 and 32 percent, respectively.

Although these absolute changes are interesting, the changes in proportion of production are indicators that are invariant to overall production. (These proportions are shown in parentheses in table 1.) In 1965, 53 percent of eastern hardwood lumber production originated from southern regions and 47 percent from the northern regions. By 1986, these proportions were nearly reversed with 46 percent originating from the south and 54 percent originating from the north. The greatest changes were the almost 7-point drop in the production originating from the south-central region and the 3- and 4-point increase in the production originating from the northeast and north-central regions. The southeast region showed virtually no change in its proportion of eastern production.

In addition to the changes in hardwood lumber production between north and south, there was a smaller proportional shift from the central regions to the eastern regions. This shift occurred because of the large decrease in south-central production, which was counteracted by increases in both the northeast and north-central regions. This decreased the proportion of production in the central areas from 60 percent in 1965 to 57 percent in 1986. Still, the two central regions dominated the two eastern regions in total and proportional production.

## FACTORS AFFECTING REGIONAL SHIFTS

There are several potential explanations for changes in regional hardwood lumber production. Among these are the impacts of increased international and domestic demand for quality lumber,

Table 1.--Estimated annual hardwood lumber production in the Eastern United States, by region, 1965-86, (regional proportions in parentheses).

| Year | Northeast | North-central | Southeast | South-central | Total* Eastern U.S. |
|---|---|---|---|---|---|
| | | | Million board feet | | |
| 1986 | 2262 (22) | 3171 (32) | 2117 (21) | 2474 (25) | 10024 |
| 1982-85 | 2105 (24) | 2714 (31) | 1745 (20) | 2176 (25) | 8739 |
| 1978-81 | 2008 (24) | 2428 (29) | 1785 (21) | 2230 (26) | 8451 |
| 1974-77 | 1788 (23) | 2274 (29) | 1644 (21) | 2178 (28) | 7884 |
| 1970-73 | 1723 (21) | 2271 (28) | 1797 (22) | 2276 (28) | 8067 |
| 1966-69 | 1764 (20) | 2306 (27) | 1945 (22) | 2636 (30) | 8650 |
| 1965 | 1800 (19) | 2409 (28) | 2042 (21) | 3028 (32) | 9279 |

*Data may not add due to rounding.

changes in the markets for lower value species or grades, and market reactions to long-term timber management decisions.

Since 1965, hardwood lumber exports have increased by more than 500 percent. Although not all lumber being exported is of the highest quality, the average price received was more than $637 per thousand board feet in 1986 (U.S. Dep. Comm., Bur. Cens. 1981-87). The export price was above that for 1C (or furniture grade) lumber of nearly every species other than walnut. This indicates that a large proportion of the exports was comprised of higher grade lumber from the more select species (Lemsky 1953-87, Setzer 1987-88).

A recent study by Araman (1987) indicates that even though the south has 14 percent more commercial hardwood sawtimber than the north, the north has an 89 percent greater volume of what is characterized as "select export species." Although one could argue with Araman's selection of select species, the stronger demand for northern as compared to southern hardwood sawtimber is also apparent in the marketplace.

The domestic market for higher grade material has also changed during the past 20 years. As late as 1965, large quantities of lumber were used for localized uses such as building or fence construction, dunnage, and bridges (Luppold and Dempsey - in press). Oak and poplar were among the major species used for these purposes, but nearly every species had some use. This situation allowed sawmillers outlets for nearly all the lumber produced from mixed-species stands of hardwoods.

Changes in technology, building codes, softwood availability, and metal and plastic products have caused many of the localized markets for hardwood lumber to disappear. Today, in the absence of nearby pallet plants, there is a limited market for many of the less valuable species. The species that are in strong demand by the domestic furniture, cabinet, and millwork markets tend to be the same select species in demand by international buyers. As Araman indicated, the concentration of these species is in the northern areas.

Even in areas where there are greater proportions of high-quality timber of the more desirable species, high-grade lumber cannot be profitably produced without an outlet for low-grade lumber. The largest user of low-grade lumber is currently the pallet industry (Cardellichio and Binkley 1984, Luppold 1987). Four of the top five pallet-producing states are located in the north (Luppold and Anderson 1986). Furthermore, pallet producers in southern areas often have the opportunity to substitute less expensive southern pine for hardwood, whereas pallet makers in northern areas do not normally have pine locally available. This decreases the market for the low-grade hardwood materials in the south and puts an upward cost pressure on lumber production.

A third argument relating to the regional shift in hardwood production is the effect of the strong emphasis on planting southern pine in the south during the past three or more decades (Squires 1969; U.S. Dep. Agr., Forest Service - in press). During the initial stages of this effort, large amounts of hardwood stumpage apparently came onto the market at relatively low prices. Low stumpage prices could have, in themselves, increased production above post-1889 historic levels. Also, the continual strong emphasis on the regeneration, management, and industrial use of pine may have left the south with a significant portion of its hardwoods on poorer growing sites and created a defacto de-emphasis on the management and industrial use of hardwoods.

## IMPLICATIONS

Although southern pine management may have been a contributing factor to the shift in lumber

production from the south to the north, most of this shift can be related to domestic and international demands for higher quality lumber of a few select species including red oak, cherry, and ash. The result of this growing demand is evident in rising prices. For example, the current dollar prices of 1C northern red oak and Appalachian black cherry have increased by 199 and 206 percent, respectively, between 1973 (the start of the export boom) and 1988 (Lemsky 1953-87, Setzer 1987-88). The price of 1C southern red oak--not as popular in the marketplace as northern red oak, but still a partial substitute--increased by 169 percent during this period. Prices of the less preferred species, such as Appalachian poplar and southern sap gum, have only increased by 28 and 51 percent, respectively.

The continued demand for a few select species and grades of hardwood lumber may result in a contradiction of timber shortages in the midst of timber abundance. As stands with higher proportions of the more desired species are sought out, stands with lower proportions of these species will be left unharvested.

A potential result of this type of market action could be growing timber inventories with apparently escalating prices, while at the same time having timber stands that do not sell at any price. Because of the current species mix between the south and the north, southern inventories could be expected to grow faster than northern inventories after adjusting for biological factors.

Of course, the current hardwood lumber market trends cannot continue indefinitely. Prices of the select species will eventually increase to the point where substitution of the less desirable species will become an alternative, or the demand for the final products such as wood furniture will level off or decline. The value of the dollar and consumer preference will affect the timing and nature of these changes. Increased utilization of hardwood timber in pulp, paper, structural panels, and other uses may also make stands with lower proportions of the desired species more economical to harvest.

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## Appendix A - Development of Multipliers

The first step in the development of adjustment multipliers was to match data from alternative sources with CIR data for particular states and years. The CIR data for which there were matching alternative data sources were summed for individual years. The data from alternative sources also were summed for individual years. An unadjusted multiplier (UMULT), for individual years, was calculated using the following formula:

$$UMULT = (SCIR - SALT) / SCIR$$

where:

UMULT = Unadjusted multiplier for a given year.

SCIR = Summed CIR data for states with alternative data for that year.

SALT = Summed alternative data for that year.

In any given year, the states for which alternative data sources were available ranged from 9 to 58 percent of the national total. This percentage (PROP) was calculated by dividing the summed CIR data by the total Eastern U.S. hardwood lumber production for individual years. The adjusted multiplier used to transform CIR data into the results shown in table 2 was calculated for individual years by using a 3-year weighted average. (The UMULT figure for 1986 was substituted for the AMULT figure because of changes in the sample frame.) The rationale for choosing this approach is that it isolates the variation due to poor sampling techniques nationwide better than the unadjusted multiplier. This multiplier, AMULT, was calculated as follows:

$$\text{AMULT} = \frac{((\text{UMULT}_{t-1} \times \text{PROP}_{t-1}) + (\text{UMULT}_{t} \times \text{PROP}_{t}) + (\text{UMULT}_{t+1} \times \text{PROP}_{t+1}))}{\text{PROP}_{t-1} + \text{PROP}_{t} + \text{PROP}_{t+1}}$$

Appendix Table 2.--Comparison of Eastern U.S. hardwood lumber production, by state, between Current Industrial Reports (CIR) and other sources (in million board feet).

| State | Year | CIR | Other | Percent difference | 1984 estimate |
|---|---|---|---|---|---|
| Maine | 1984 | 108 | [2]121 | 13 | [7]121 |
| New Hampshire | 1982 | 18 | [1]52 | 189 | [6]72 |
| Vermont | 1982 | 42 | [1]74 | 76 | [6]67 |
| Massachusetts | 1984 | 50 | [1]55 | 10 | [7]55 |
| Connecticut/Rhode Island | 1984 | 47 | [1]59 | 26 | [7]59 |
| New York | 1985 | 226 | [2]524 | 132 | [6]587 |
| Pennsylvania | 1980 | NA | [1]650 | NA | [5]650 |
| New Jersey | 1984 | 10 | [2] 23 | 130 | [7]23 |
| West Virginia | 1984 | 384 | [2]425 | 11 | [7]425 |
| Delaware/Maryland | 1984 | 86 | [3]127 | 48 | [7]127 |
| Michigan | 1984 | 220 | [3]465 | 111 | [7]465 |
| Wisconsin | 1981 | NA | [1]414 | NA | [5]414 |
| Minnesota | 1985 | 95 | [3]199 | 109 | [6]214 |
| Ohio | 1983 | 249 | [1]374 | 50 | [6]362 |
| Indiana | 1984 | 391 | [3]390 | 0 | [7]390 |
| Illinois | 1984 | 64 | [2]144 | 125 | [7]144 |
| Kentucky | 1984 | 246 | [2]460 | 87 | [7]460 |
| Missouri | 1983 | 150 | [3]482 | 221 | [8]450 |
| Iowa | 1984 | 27 | NYA | NYA | [9]27 |
| Kansas/Nebraska | 1984 | 25 | [2]58 | 132 | [7]58 |
| Virginia | 1984 | 421 | [1]709 | 68 | [7]709 |
| North Carolina | 1983 | 366 | [1]580 | 58 | [6]607 |
| South Carolina | 1984 | 192 | [1]279 | 46 | [7]279 |
| Georgia | 1984 | 227 | [2]348 | 53 | [6]264 |
| Florida | 1984 | 32 | [2]28 | -13 | [7]28 |
| Tennessee | 1984 | 387 | [2]613 | 58 | [7]613 |
| Alabama | 1984 | 333 | [2]445 | 34 | [7]445 |
| Mississippi | 1984 | 338 | [4]509 | 51 | [7]509 |
| Arkansas | 1985 | 236 | [3]502 | 113 | [6]436 |
| Louisiana | 1984 | 154 | [3]262 | 70 | [7]252 |
| Texas | 1985 | 130 | [2]175 | 35 | [6]151 |
| Oklahoma | 1984 | 52 | [1] 54 | 4 | [7]54 |
| Total | 1984 | 6061 | | | 9517 |

NA - Comparable figure not published in CIR in 1980 or 1981.
NYA - Post 1980 report on lumber production or log use not yet available.

Data source footnotes:

[1]Drain figures reported by USDA Forest Service staff covering the respective state.

[2]Figures provided by state utilization foresters through drain and mill studies.

[3]Figures developed from state tax records.

[4]Figures provided by the Tennessee Valley Authority.

1984 estimate footnotes:

[5]Used production figure from most recent period.

[6]Calculated 1984 figure using changes in CIR figure times figures from other sources.

[7]Used 1984 other source estimate.

[8]Estimated by state utilization forester (lowest estimate).

[9]No data source available, so CIR figure assumed.

# ECONOMIC POTENTIAL OF INCREASED TIMBER AVAILABILITY IN NORTHCENTRAL PENNSYLVANIA[1]

Charles H. Strauss[2]

ABSTRACT. Long term forecasts of timber availability were developed for one of Pennsylvania's most valuable hardwood regions. An eight county region in north-central Pennsylvania was found to have a sawtimber supply capability that could triple over the next 60 years. Under a best case economic development scenario, a doubling of harvests could increase the value added in manufacturing within the region by 28%, representing an addition of $300 million per year to the regional economy.

## INTRODUCTION

TIMBER RESOURCES ARE GAINING increased attention within northeastern United States. In part, this relates to the gradual transition of these intermediate aged hardwood forests to a more marketable status. Allied with this change has been a moderate increase in the output of forest products and in the export of logs and lumber to foreign markets. The renewed interest in timber may also be attributed to a general search for alternate means of revitalizing Northeastern economies. Whether these forests can serve as a catalyst to development will depend on the long term production capability of the forests and the economic advantages available to resident industries.

In Pennsylvania, forests extend over 16.8 million acres, representing 58 percent of the state. While Pennsylvania ranks only 33rd in land area among all states, it is 12th in total commercial timberland (USDA Forest Service definition). This includes 20 billion cubic feet (bcf) of hardwood growing stock; more than any other state in the nation. About 50 percent was in sawtimber stands, representing 7 bcf of hardwood sawtimber (Powell and Considine 1982). The size and stature of this resource are also reflected in lumber production, with Pennsylvania ranked first among all states in hardwood lumber output during 1986 (National Forest Products Association 1987).

The State's present forest developed with only a minimum degree of forest management. Prior to 1880, timber harvesting was largely directed toward the more accessible pine and hemlock stands. Further commercial clear-cutting followed during the period 1880 to 1900, in tandem with the development and use of railroads for logging and hauling. By 1920, the remaining virgin and partially cut softwood stands had been clearcut (Marquis 1975). Much of this forest gradually regenerated to hardwood types, with the primary management effort directed to fire protection. Now, large portions of the forest are again reaching harvestable age.

The impending maturation of a large proportion of the state's timberland has led to some speculation that the timber production cycle experienced in Pennsylvania at the turn of the century could be repeated. However, neither the short term nor the long term productive capability of the major timbersheds have been quantified. The dynamics of forest management need to be explored in terms of their impact on future timber yields and economic benefits.

[1] Paper to be included in the Seventh Central Hardwoods Forest Conference sponsored by USDA Forest Service and Southern Illinois University, Carbondale, Illinois. March 5-8, 1989. Support provided by McIntire-Stennis funding as Project No. 2626.

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A series of studies was initiated by Penn State's School of Forest Resources to evaluate timber availability within the northcentral region of Pennsylvania and to assess the current structure and future potential of the region's forest products industry. This paper describes (1) the results of a timber forecasting model organized to determine future timber availability within the region and (2) allied estimates of the economic activity that could be generated by an expanded harvest and increased utilization of timber within the region.

## DESCRIPTION OF THE STUDY REGION

The Allegheny Region, an eight county area located along the northern tier of Pennsylvania (Figure 1), was selected for study because it comprises one of the State's more valuable timbersheds. At the time of the 1978 state-wide inventory, the region was 84% forested and contained the largest per acre and total growing stock volumes of any of the eight forest survey units in the state (Powell and Considine 1982). It also included over 20% of the state's timberland, about 3 million acres. The more valuable northern hardwood types dominated, representing 69% of the timberland. Upland oak types were found along the southern portion of the region and comprised 21% of the timberland area. Nearly 55% of the acreage was classified as sawtimber stands, with 37% in poletimber and 7% in seedling/sapling (Considine and Powell 1980).

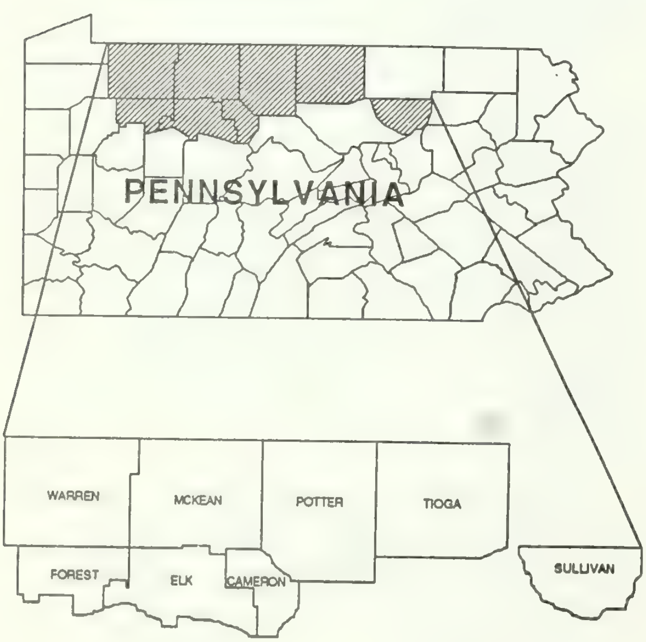


Figure 1. The Allegheny Region of Pennsylvania.

Timberland within the region was actively managed by both the public and private sectors. Forty-two percent of the timberland was under public management, including the U.S. Forest Service, the Pennsylvania Bureau of Forestry and the Pennsylvania Game Commission. Over 17% of the timberland was managed by the forest products industry and an additional 10% was owned by nonforest-based industries. The remaining 31% was owned by farmers and other private non-industrial classes (Considine and Powell 1980). Over 60% of the private timberland was situated on tracts exceeding 200 acres in size, with 45% in tracts over 1000 acres. An active forest management attitude was prevalent within these properties, with 72% of the private timberland controlled by owners who had harvested in the past (Birch and Dennis 1980). Owners who had not harvested in the past most often cited immature timber as their primary constraint.

A sizeable forest products industry was identified within the Allegheny Region (Westman et al. 1985). In 1981, there were 480 forest product establishments within the region, comprised of 356 logging contractors, 89 sawmills and 35 secondary manufacturers (Table 1). Sawtimber consumption within the region was estimated at nearly 150 million board feet (mmbf), Doyle scale, per year. However, over 85% of the lumber output was exported, with the economic benefits of secondary manufacture captured elsewhere.

Overall, the forest products industry was of moderate importance to the region's economy. Eighteen percent of the value added from manufacturing within the region was derived from the forest products industry, amounting to $196 million in 1981. Nearly 4000 full-time workers were employed by this industry group, representing 15% of the total employment and wages/salaries developed by the region's manufacturing industries. Over one half of the financial contributions from the forest product industry were organized from the pulp and paper sector, underscoring the relative importance of this particular sector.

An initial study of sawtimber availability in the Allegheny Region by Strauss and McWilliams (1987) provided a starting point for timber assessments. The TRAS stand projection model (Larson and Goforth 1974) was used to estimate sawtimber availability over a three decade period, 1980 to 2010. Model forecasts indicated an increase in sawtimber availability, to an average annual level of 425 mmbf (International 1/4") in the 1990's. However, in the third decade, the potential output fell to an average annual level of 318 mmbf. The restricted planning horizon available to the TRAS-based model, in combination with the forecast of a potential decline in the region's production capability, were sufficient causes for developing an expanded timber projection model.

Table 1. Economic characteristics of the forest products industry in the Allegheny Region, 1981.

| Sector | No. of Firms | Employment (full time equiv) | Income ($ million) | Value of Shipments ($ million) | Value Added ($ million) |
|---|---|---|---|---|---|
| Logging | 356 | 861 | 14.4 | 49.9 | 34.6 |
| Sawmills | 89 | 1153 | 13.3 | 65.9 | 36.8 |
| Wood mfg. (pallet/dimen/ furniture) | 29 | 735 | 9.7 | 33.6 | 15.8 |
| Pulp/paper | 6 | 1184 | 27.4 | 216.5 | 109.3 |
| Totals | 480 | 3933 | 64.8 | 365.9 | 196.5 |

## PROCEDURES

Timber Projections - An improved timber projection system was developed for the region using the USDA Forest Service FORPLAN model (Strauss and Lord 1988). Access to FORPLAN version II was made available by the USDA Forest Service through the Allegheny National Forest headquarters at Warren, Pennsylvania.

The general FORPLAN model is organized from several basic components: an objective function, a planning horizon, analysis areas, prescriptions, yields, activity variables, and constraints (Johnson et al. 1986). The objective function for the regional model was directed to maximizing the non-discounted harvest of sawtimber over a 100-year planning horizon (Lord 1985). The planning horizon was divided into 10 decades beginning in 1980 and ending in 2079. A sawtimber measure was used in the objective function, rather than a combined sawtimber and pulpwood measure, to reflect the primary objective of most hardwood management strategies.

The region's timberland was stratified among 75 potential analysis areas based on five ownership groups, three broad forest types, and five age classes. Conceptually, an analysis area represents a distinct homogenous resource unit available to management by its owners. Ownership groups included the USDA Forest Service, the Pennsylvania Bureau of Forestry, the Pennsylvania Game Commission, private ownerships with properties over 200 acres in size, and private ownerships with properties under this size. The latter subdivision of private timberland accounted for larger property ownerships having a better potential for long term management and a greater likelihood of more intensive management. The three forest strata were the oak types, the northern hardwood types, and the allegheny hardwood type. The latter is a variant of the northern hardwoods and typically has higher percentages of black cherry, ash and yellow poplar.

Stand age classes were derived from stand size class information. Stand age classes were 1-30 years, 31-50 years, 51-70 years, 71-90 years, and 91 years or older and corresponded to respective stand size classes of seedling/-sapling, poletimber, small sawtimber, large sawtimber, and large sawtimber exceeding a 90 year rotation age (Strauss and McWilliams 1987). Forest type and age class distributions for the ownership groups were developed from inventory information maintained by the public agencies and, in the case of private ownership, from the USDA Forest Service plot data acquired during the 1978 forest survey of Pennsylvania.

Silvicultural prescriptions were represented in the regional FORPLAN model as a sequence of harvesting activities. Timing options for each prescription described the range of ages or periods in which the treatments could be implemented, e.g. rotation or thinning ages. The selection of alternative silvicultural prescriptions for the regional model was based on a previous survey of ownership groups in the Allegheny Region (Strauss and McWilliams 1987).

Four prescriptions were defined, represented by three combinations of intermediate and final harvests for even-aged management and a selection management system for uneven-aged management. The even-aged silvicultural prescriptions generally followed a rotation length of 85 to 115 years. During the rotation, the stands received from zero to two thinnings. Rotations of up to 155 years were allowed on the public ownerships to facilitate their general management strategies. Following final harvest, the model assumed that all analysis areas would be regenerated to their original type.

On the Allegheny National Forest, the proposed management plan recommended certain production ceilings and a nondeclining even flow management policy for the forest (USDA Forest Service 1985). For the state ownerships, annual harvests were constrained to 1% of their even-aged forests, consistent with their area control policy. From 10 to 25% of their properties were also managed on an uneven-aged basis.

The only management strategy on private lands was even-aged. On large tracts, the financial objectives resulted in rotation ages of 85 to 115 years. In order to model the more intensive management of larger tracts, two-thirds of the large tracts received two commercial thinnings, with the remaining acreage subject to one thinning. On small private tracts, stands were harvested at any time between 85 and 105 years. Intermediate thinnings were not scheduled on small ownerships to represent their less intense management effort.

The timber yield coefficients for the study were based on growth and yield tables originally developed by the USDA Forestry Sciences Laboratory for the Allegheny National Forest FORPLAN model. Although the 0.5 million acre national forest is in the western portion of the Allegheny Region, the yield tables were considered acceptable for the entire region.

Economic Impact - In addressing the potential economic impact of future sawtimber harvest within the Allegheny Region, certain assumptions were made regarding the magnitude and direction of this commercial enterprise. The logic of these assumptions will be addressed in a subsequent section of this paper. First, it was assumed that the regional sawtimber harvest would double over a 20 year period. This level of production, in the vacinity of 50 mmcf per year, would be within the bounds of the available supplies predicted by the turn of the century.

Three general scenarios were established to identify certain assumed levels of manufacture imposed on the region's forest products industry. In the "minimal" case all of the increased sawtimber would be harvested by resident logging companies but only one half would be processed by resident sawmills. This would double the production level in the logging sector and increase production by 50% in the sawmill sector, with the remaining logs exported from the region. A 50% expansion in output was also depicted among wood manufacturers (pallet, dimension and furniture). In the "moderate" case, a doubling of output was assumed for both the sawmill and the secondary wood manufacturing sectors. The third scenario, a "best" case situation, assumed a doubling of production in all four sectors, including the pulp and paper sector. To reflect the added harvest of roundwood required by pulp manufacturing, the logging sector's output was increased an additional 30%.

Changes in employment, income and value added, brought about by the alternate levels of production, were based upon the industry structure identified in 1981 (Table 1). In the case of the logging sector, the percentage change in output was applied directly to employment, income and value added. Thus, a doubling of output also doubled the latter three measures. For the remaining three sectors, the percentage change in output was also applied to value added, but a more moderate increase was made to employment and income. For the sawmill sector, only 90% of the output gain was applied to employment and income. Thus, a 50% increase in output resulted in a 45% increase to employment (and income). This reduction assumed a future technical ability of expanding output with a less than proportional increase in labor. In the wood manufacturing sector, labor increases were held to 85% of the output gain and, for the pulp/paper sector, the advantage was placed at 75% of the output gain.

Finally, an estimate was included of the secondary, or indirect, effects that an expanded forest products industry would have upon other manufacturing industries in the region. Economic evaluations of West Virginia's forest products industry (Zinn and Jones 1987) and Vermont's sawtimber-based industry (Michaels et al. 1986) provided estimates of these indirect, or multiplier, effects. Employment and income multipliers for the sawmill, wood manufacturing and pulp/paper sectors were in the range of 1.55 - 1.60, with the value added multipliers placed at 1.55 - 1.70. Since neither study identified logging as a separate sector, no multiplier effect was projected.

It should be noted that the multiplier values used for the Allegheny Region could be slightly higher than warranted due to their being organized from state-wide economic studies. Technically, an entire state has a more integrated economy than an area the size of the Allegheny Region, thereby providing a higher multiplier effect between industrial groups. However, this study also took a conservative stance by not including the tertiary, or induced, effects generated by the expenditure of employee incomes within the region. In the previously cited studies, the composite effect of indirect and induced demands provided multipliers ranging from 2.2 - 2.6 for the forest products industry. Although the indirect multiplier values used within the Allegheny Region may be somewhat overstated, they are probably within bounds of the composite multiplier.

## RESULTS

Timber Projections - A major increase in available sawtimber was forecast for the Allegheny Region over the 100-year period (Table 2). Starting from a level of 280 million cubic feet (mmcf) in decade 1, the model projected general increases in sawtimber availability throughout the next six decades, reaching a peak volume of more than 950 mmcf in both decades 6 and 7. A modest decline was registered in the eighth decade, followed by an additional drop of 27% in the final two decades. Estimated peak production was more than triple the level forecast in the first decade.

Sawtimber by ownership groups was in direct proportion to the amount of land controlled by each group (Table 2). The private to public ratio increased slightly over the study period, ranging from 62:38 for the first three decades to 58:42 for the last three decades. This shift reflected the effect of the even flow management strategies on public lands, coupled with a gradual decline in timber availability from private lands.

Over the 100-year period, 85% of the available sawtimber was provided from final harvests, with the remainder coming from

Table 2. Projected sawtimber harvests from the Allegheny Region by decade and ownership group, 1980-2079.

| Decade / Ownership: | Allegheny National Forest | Pa. Bureau of Forestry | Pa. Game Commission | Private Small Tract | Private Large Tract | Total |
|---|---|---|---|---|---|---|
| Size: m acres | 433.6 | 489.4 | 215.0 | 1,068.5 | 683.1 | 2,889.6 |
| | | | Volume in mmcf | | | |
| 1 | 46.8 | 62.8 | 17.1 | 52.5 | 101.2 | 280.4 |
| 2 | 89.4 | 58.9 | 24.0 | 77.6 | 202.6 | 452.5 |
| 3 | 99.4 | 79.0 | 52.6 | 225.8 | 184.5 | 641.3 |
| 4 | 98.4 | 115.5 | 57.6 | 141.2 | 166.6 | 579.3 |
| 5 | 105.7 | 111.8 | 53.3 | 261.9 | 226.8 | 759.5 |
| 6 | 118.4 | 118.4 | 46.2 | 188.0 | 492.8 | 963.8 |
| 7 | 126.3 | 153.8 | 80.5 | 176.5 | 414.6 | 951.7 |
| 8 | 129.2 | 123.4 | 49.2 | 29.7 | 548.6 | 880.1 |
| 9 | 112.8 | 152.8 | 74.1 | 163.5 | 132.3 | 635.5 |
| 10 | 109.2 | 129.3 | 42.2 | 36.4 | 341.7 | 658.8 |
| Total Sawtimber | 1035.6 | 1105.7 | 496.8 | 1353.1 | 2811.7 | 6802.9 |
| Swtbr. from thin./sel. | 97.1 | 223.7 | 191.7 | 0.0 | 472.8 | 985.3 |
| Total Pulpwd. | 544.8 | 982.6 | 418.6 | 1110.8 | 2178.5 | 5235.3 |
| Pulp from thin./sel. | 146.6 | 503.6 | 256.6 | 0.0 | 1088.9 | 1995.7 |

thinnings and selection harvests (Table 2). The proportion of sawtimber coming from final harvests increased over the study period, with 70% organized in the first three decades and 89% in the final seven decades.

A total of 5.2 billion cubic feet of pulpwood was available for harvest during the 100-year period (Table 2). The distribution of the pulpwood output by ownership groups was also in proportion to the size of the ownerships. About 38% of the pulpwood originated from intermediate thinnings and selection harvests. A moderate decline in pulpwood availability was registered due to the gradual advance in the forest's age structure and associated reduction in commercial thinnings.

Within the private ownerships, a cyclical pattern of available timber was evident. This was attributed to the initial imbalance in age classes within these ownerships, in combination with the assumed management strategy of releasing all timber to the market at rotation age. A gradual increase in private sawtimber harvests was evident over the first six decades in tandem with the substantial acreages of large sawtimber (Table 2). Following, a considerable drop was forecast, as removals exceeded stand replacement.

On public lands, the sustained production strategies resulted in a uniform increase of sawtimber throughout the study period. Within state properties, an increased output was evident, with the area control strategy also resulting in a backlog of old growth stands (> 110 years). Fluctuations in output levels were largely attributed to variations in commercial thinning operations. On the National Forest, the nondeclining even flow constraint held total output to a range of 130-158 mmcf per decade. By the fourth decade, the forest was capable of maintaining its upper limit of production through rotation harvests, thereby eliminating the need for thinning operations. Longer rotation lengths were evident on public ownerships during the latter decades, with the average stand age of harvested material exceeding 140 years.

The cumulative effect of the forest's growth and proposed harvest was a better balance of age classes within the aggregate forest. Initially, nearly 95% of the timberland was in poletimber and sawtimber size class material. By the midpoint of the study, approximately 45% of the timberland was harvested and reestablished to seedling/sapling and poletimber sized stands. The primary imbalance by the midpoint was in the 51-70 year class stands (small sawtimber) that developed from the initial shortages of seedling/sapling class stands in the first decade. By the conclusion of the study the distribution among the stand classes was 32% in seedling/sapling, 27% in poletimber, and 41% in sawtimber stands. This general balance was found on both public and private forests.

Economic Impacts - The proposed doubling of sawtimber output over a 20 year period could result in varying economic impacts, depending on the extent of accelerated manufacture by resident industries. In the "minimal" case, the doubling of output by resident loggers and a 50% increase in sawmill and secondary wood manufacturing resulted in over 2000 new jobs and a $29 million increase to wage and salaries for regional manufacturing (Table 3). This expansion also created an additional $79 million in the regional value added from manufacturing, representing a 7% gain over the 1981 level. Forty four percent of this gain was organized from the logging sector, with 33% credited to the combined sawmill and wood manufacturing sectors and the remaining 23% to the indirect demand placed on other manufacturers.

By doubling the output from the sawmill and wood manufacturing sectors, as identified in the "moderate" case, the region would realize a further increase in employment of 1,295 persons, with an additional $17 million placed in salaries and wages. Value added by manufacture would increase by another $43 million, for a total gain of 11% beyond the 1981 level.

The third expansion, this time in the pulp and paper sector, provided 1700 new jobs, $34 million more in wages and salaries and $182 million more in value added. Total value added was $304 million, representing a cumulative increase of 28% above the 1981 level.

## DISCUSSION

Future Markets - Some assessment of the region's overall ability to market an increased supply of sawtimber can be made from recent evaluations of hardwood markets. The national forecast for hardwoods calls for a tripling of product demand over the period 1980-2030 and a doubling of sawtimber supply, leading to an increase in the real prices for certain products (USDA Forest Service 1982). Real price increases have now been confirmed for various species indigeneous to the Allegheny Region over the period 1964-86 (Kingsley and DeBald 1987). In part, the increased production in hardwoods has been bolstered by an increased demand for logs and lumber from foreign markets (Araman 1987, Gregory 1987). Overall, the national and international demands for hardwood products complement the region's timber production capability and should stimulate the marketing of available supplies.

Previous forest surveys of Pennsylvania have shown a gradual increase in sawtimber harvests from the Allegheny Region during the past three decades (Ferguson 1958, Ferguson

Table 3. Potential economic impacts resulting from an expansion of forest products manufacturing in the Allegheny Region.

| | Δ Output | Δ Employ | Δ Income ($ mil) | Δ Value Added ($ mil) |
|---|---|---|---|---|
| Minimal Case: | | | | |
| Logging - | 100% | 860 | 14 | 35 |
| Sawmills - | 50% | 510 | 6 | 18 |
| Wood Mfg. - | 50% | 310 | 4 | 8 |
| Pulp/paper - | 0% | | | |
| Total Direct | | 1680 | 24 | 61 |
| Total Indirect | | 450 | 5 | 18 |
| Total | | 2130 | 29 | 79 |
| Moderate Case: | | | | |
| Logging - | 100% | 860 | 14 | 35 |
| Sawmills - | 100% | 1035 | 12 | 36 |
| Wood Mfg. - | 100% | 620 | 9 | 16 |
| Pulp/paper - | 0% | | | |
| Total Direct | | 2515 | 35 | 87 |
| Total Indirect | | 910 | 11 | 35 |
| Total | | 3425 | 46 | 122 |
| Maximum Case: | | | | |
| Logging - | 130% | 1120 | 18 | 45 |
| Sawmills - | 100% | 1035 | 12 | 36 |
| Wood Mfg. - | 100% | 620 | 9 | 16 |
| Pulp/paper - | 100% | 885 | 20 | 110 |
| Total Direct | | 3660 | 59 | 207 |
| Total Indirect | | 1430 | 21 | 97 |
| Total | | 5090 | 80 | 304 |

1968, Bones and Sherwood 1979). A 20% increase in harvests occurred between the 1950's and the 1970's, with the average annual consumption in sawtimber of 21 mmcf increasing to 25 mmcf by the 1970's (Figure 2). The 1981 study of the region's forest products industry also supported this general trend, showing an annual sawtimber consumption of 24 mmcf, excluding log shipments to outside regions (Westman et al. 1985).

A positive trend in pulpwood removals has also been evident in the Allegheny Region (USDA Forest Service series). Between the 1960's and 1970's, pulpwood harvests doubled, increasing from 76 mmcf per decade to 152 mmcf. Furthermore, the initial six years removal rate in the 1980's was 56% higher than for the same period in the 1970's.

Availability of Timber Supplies - The TRAS model of the region's forest system (Strauss and McWilliams 1987) showed a potential doubling of sawtimber output when comparing the 1970's harvest rate to the 1980's avail-

ability level. However, nearly 45% of this increase was obtained from intermediate harvests. The second decade's available supply was near constant, followed by a 24% decline in the third decade (Figure 2). Over the 30 year period, the TRAS-based model provided 25% more sawtimber than the FORPLAN model. This was largely attributed to the alternate structure of the two models and, to a lesser extent, their alternate sources of growth and yield information.

Basically the TRAS model was less flexible in its identification of available sawtimber, with potential supplies organized from the various management plans at their earliest release date. In contrast, the timber maximizing design of the FORPLAN model took advantage of the forest's growth function over the 100-year study period and deferred some proposed harvests to later periods in time. In general, both studies supported the doubling of sawtimber availability over a 20-30 year period. In the TRAS-based model, the gain was more immediate, with a major portion organized from lower valued intermediate harvests. The FORPLAN model showed a stronger, long term timber supply capability, largely supported by final harvests.

Economic Potentials - The proposed doubling of sawtimber harvests over the next 20 years could provide a variety of economic gains to the region, ranging from a moderate increase of 7% in the value added by manufacture to a maximum of 28%. The explanation for this variation is fairly simple; as more timber is processed by resident industries, the greater the value added to the economy.

The forest products industry organized within this region consists of two major divisions: a sawmill/wood manufacturing complex dependent on sawtimber and a pulp/paper complex based upon roundwood. These divisions are largely separate in their timber demands, however, their combined raw material needs support the intergrated harvesting design of most forest plans. A similar compliment would also be created by the roundwood needs of a particleboard or flakeboard industry. Within the Allegeheny Region, one of the key limits to the further development of either pulp and paper or particleboard manufacturing is the shortage of softwoods. However, certain advances in the manufacture of disposal paper product and variable density boards hold sufficient promise for the increased use of hardwoods by these industries (USDA Forest Service 1982).

Also, the implied joint expansion of the region's sawmill and wood manufacturing sectors, as presented by this paper, should not be interpreted as a formal technical linkage. During 1981, less than 15% of the resident sawmill production was marketed within the region. As such, a sufficient

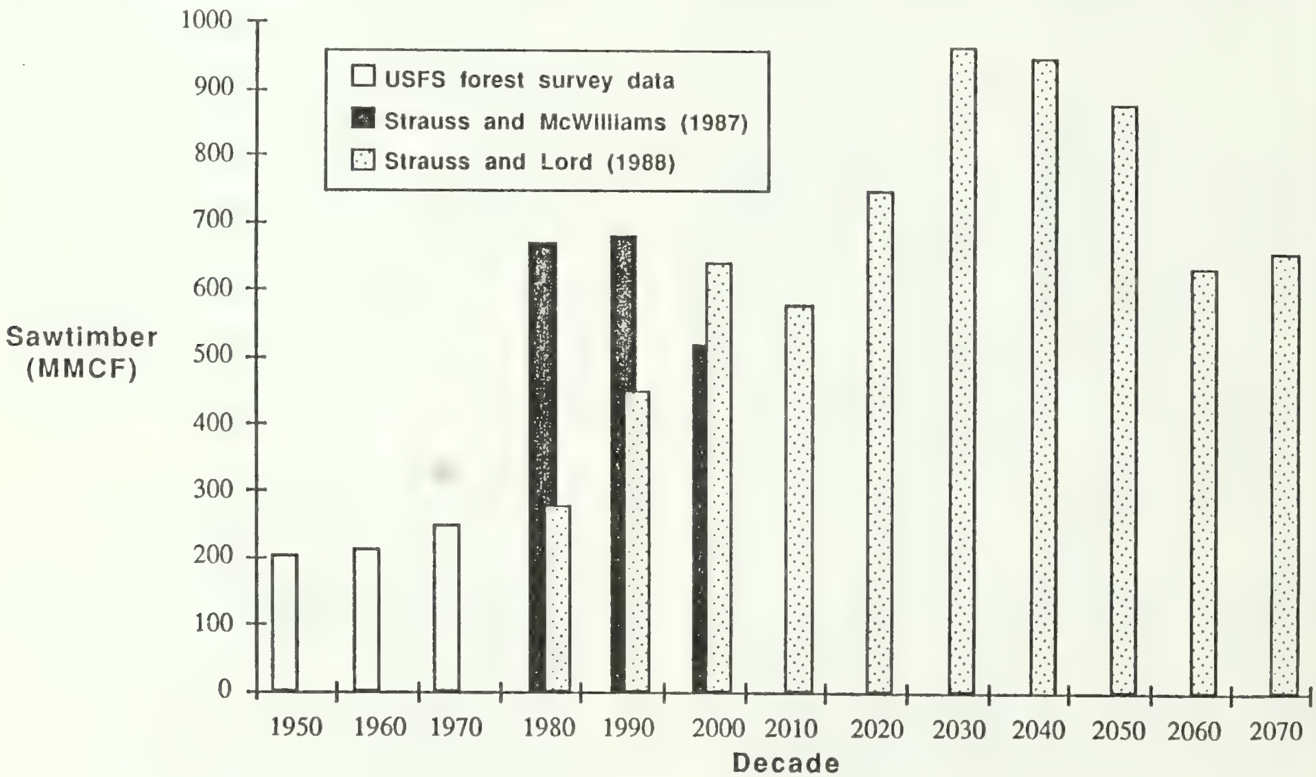


Figure 2. Historic and projected sawtimber harvests for the Allegheny Region.

supply of lumber already exists for an expansion of the secondary wood manufacturing sector. In a similar fashion, there already exist abundant supplies of roundwood for an initial expansion of the pulp and paper or particleboard sectors.

## CONCLUSIONS

The timing and magnitude of the future timber supplies predicted by the model are, in general, supported by information on this resource base. First, the existing volume of timber within the Allegheny Region has been confirmed through the continuing series of forest surveys and updates. Second, the growth inherent to this resource supports the predicted increase in timber availability. This progression has been modeled and shown to be consistent with the predicted advance of age classes and prescribed rotation ages.

The most debatable aspect of the model is its inability to predict the actual volumes of timber that will be marketed. The availability data reflect an optimal scenario, largely based on the management desires of the forestry profession. Although this advice is closely considered on public forests, it may not be consistent with the future decisions of the private sector, nor with the economic realities of timber markets. In short, more or less timber could be marketed depending on the long term demand for this commodity.

Regardless, a major sustained expansion in sawtimber production can probably be expected from the Allegheny Region. This note of optimism is supported by the increasing world demand for hardwood timber resources and by this region's ability to provide a quantity and quality of timber unmatched by any other timbershed. An unresolved question is whether the expansion in timber harvests will foster an increase in the region's forest products industry.

Economic development within the overall forest products sector will depend on something more than just the provision of ample timber supplies. Assuming that an expanded demand will develop for the finished products, the development of manufacturing centers within the Allegheny Region will require a particular blend of capital, labor and raw material inputs under the secondary influence of investment and tax incentives, transportation networks and proximity to available markets. If this composite of factors can be found elsewhere and in a more advantageous setting, then these industries will locate or expand according to the relative advantages provided by alternate sites. Timber can serve as an important catalyst to industrial development but it may not be the most dominant force. Should future industrial growth locate elsewhere, then the best that can be expected for the Allegheny Region will be the continued export of logs and lumber to outside regions.

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# THE ECOLOGY OF FOREST RECREATION:

# A FRAMEWORK FOR RESEARCH IN CENTRAL HARDWOOD FORESTS 1/

Herbert W. Schroeder 2/

Abstract.--This paper discusses ecological concepts that may help us to understand recreation behavior in central hardwood forest environments. Treating recreation and biological processes as interrelated components of the total ecosystem may make it easier to integrate recreation with timber and other resources in the management of central hardwood ecosystems.

The Eastern Region of the USDA Forest Service has developed an interdisciplinary approach to implementing Forest Plans, which it calls "Integrated Resource Management" (IRM). This approach requires specialists in different resource disciplines to work as a team to "coordinate and integrate planning actions consistent with the principles of the Multiple Use Sustained Yield Act" (Forest Service 1985). To accomplish their purpose, the interdisciplinary team needs to know how the management of any one forest resource will affect other resources. For this reason, research needs to examine interactions between different resources and uses in forest ecosystems. In other words, Integrated Resource Management requires that research also be integrated across disciplinary lines, and not compartmentalized into isolated disciplines.

Differences in technical language and concepts often hinder the integration of research across disciplinary lines, even when processes under study in different disciplines have features in common. In particular, there appear to be many similarities between the processes studied by ecologists and those studied by recreation researchers in forest environments. Recreationists have specific "habitat" requirements. They move through ecosystems and landscapes in much the same way as wildlife species, interacting with each other and with their biological and physical surroundings. Therefore, it may be useful to examine recreation behavior in the light of ecological concepts, models, and theories.

The application of ecological concepts to humans is not new. Most ecology texts contain sections on human population growth, pollution, and resource depletion (e.g. Kormondy 1984, McNaughton and Wolf 1973). Human ecology is a well-established field, and has developed useful analyses of how human cultures and settlements function and interact with their physical and biological surroundings (e.g. Boyden et al. 1981). In the field of recreation research, there is growing recognition that human recreation behavior must be understood in relation to the environment in which it takes place, and that the concepts and theories of ecology may contribute to that understanding (Machlis et al. 1981, Field et al. 1985, Hammitt 1983).

Casting models of recreation in conceptual terms similar to models of wildlife and other ecosystem components may give us new insight into the nature of recreation behavior and its relation to the environment in which it occurs. At the same time it will be easier for recreation scientists to communicate with biologists and resource managers, and to link their research with models and data about biological aspects of natural resource recreation settings. This paper outlines a conceptual framework for the study of recreation behavior, using concepts from the field of ecology, with some examples and suggestions for forest recreation research in the central hardwood region.

## ACTIVITIES

Recreation behavior occurs in repeatable and identifiable patterns, called "activities." Ideally, a recreationist can be classified according to the activity she or he is engaged in, and may be regarded as a member of a distinct population of individuals engaged in that activity. Although this is not always true, it is a useful assumption from which to start. The unit of analysis is not the individual per se, but the individual engaged in a specific activity. If an

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individual switches from one activity to another, he or she thereby becomes a member of a different population.

In the central hardwoods region several important activities are easy to identify, such as hunting, fishing, hiking, camping, river floating, picnicking, and motorized trail use. Other activities are less easily observed and identified (for example mushroom gathering), but are nevertheless important forest uses for some people. A first step in an integrated recreation research program for central hardwoods would be to identify which activities are most important, and which should be the subject of management efforts to enhance recreation opportunities.

## ADAPTATION AND NICHES

Recreation activities are adapted to their settings in much the same way that biological organisms and their behaviors are adapted to their environments. Individuals will engage in a recreation activity only as long as they obtain sufficient satisfaction from the activity. The "fitness" of an activity in a particular setting is a measure of how enjoyable that activity is under the conditions of the setting. If the activity is unsuited to the setting (e.g. downhill skiing on flat terrain) satisfaction will be absent, and the activity will not take place. Thus a process akin to natural selection operates on recreation behavior; and activities either become adapted to the specific settings in which they take place, or they cease to occur.

The fitness of an activity in relation to its environment leads to the ecological concept of "niche" (Hutchinson 1957). Perhaps the simplest definition of a recreation niche would be "the set of environmental conditions under which a particular activity is able to occur." Some activities have developed different specialized forms that are adapted to different niches. Downhill and cross-country skiing are good examples of this. In the central hardwoods region some activities have specialized niches; for example, canoeing and tubing require river corridors with sufficient water depth and flow, and hiking requires trails of sufficient length. Hunting and fishing are obviously tied to the presence of game and fish species. Other activities have much broader niches. For example, the new all-terrain vehicles (ATV's) can travel on roads and trails, overland, and even in stream beds.

Research can help establish which physical, biological, and social factors are important in creating suitable niches for various recreation activities, and how these factors are influenced by management activities and recreational use. Some environmental factors have impacts on certain specific activities, while other factors may contribute to the quality of habitat for a wide variety of activities. For example, visual quality is an important environmental attribute that can enhance the enjoyment of virtually any activity done in a forest. Because timber harvesting in central hardwoods has a major impact on the appearance of the landscape, research on users' perceptions of managed timber stands should be a high priority in this region. A knowledge of the visual outcomes of alternative management practices, particularly even-age versus uneven-age management, would be valuable input to the forest planning process.

Niches must also be defined in terms of time. Certain activities take place only during certain seasons of the year, and most people find weekends to be the most suitable time of the week for recreational excursions into the forest. Monitoring use levels in important recreation habitats, such as the Ozark National Scenic Riverways, to detect patterns in use over time of day, day of the week, and season of the year can provide useful information for managing high-use recreation environments (Chilman et al. 1986, Marnell et al. 1978).

## POPULATION DYNAMICS

Growth and interaction of populations is a topic of major concern in ecology. The growth rates of wildlife populations are governed by biological processes of reproduction and mortality. For populations of people engaging in recreation activities, the main processes governing population dynamics are not biological but psychological, i.e. the number of people engaging in an activity at a particular place and time is the outcome of individual preferences and choices. Nevertheless, the population dynamics of recreation may have features in common with the dynamics of biological populations.

Recreation research has produced models for predicting how people will choose among recreation sites having various attributes. The models are usually static, that is, they describe the probability of choice at a single point in time, assuming that the attributes of the sites are given and fixed. Ecological population models, on the other hand, are dynamic (May 1974). They describe a population's rate of change, based on the attributes of the environment and other populations, and trace the growth and decline of interacting populations. Recreation choice models could also be extended to represent dynamic interactions among populations of recreationists engaging in different activities.

## PERCEPTIONS OF DYNAMIC ENVIRONMENTS

The dynamic, or time-related, factor also enters into visual quality issues. Most existing research on forest landscape esthetics has looked at the scenic quality of individual scenes at a single point in time. To truly understand the visual outcomes of timber management, however, this research must incorporate the full time span of the timber management cycle. For example, everyone knows that clearcuts are unattractive immediately after harvest, but how does the scenic quality of

the cut change as the forest regenerates? How does the public perceive these gradual changes in the forest? To answer these questions, research should examine ways of linking models of scenic perception to growth and yield models for forest stands.

## COMPETITION AND CONFLICT

Ecologists classify interactions among populations according to how the presence of one population affects another. Some common types of interaction include predation, competition, parasitism, and mutualism. It is possible to think of recreational analogues for all of these, but competition is probably the most significant form of interaction among populations of recreationists. Competition may be direct, as when the behavior of people engaged in one activity is antagonistic or offensive to people in other activities, or it may be indirect, as when two otherwise compatible activities must compete for the same space and other resources.

When the niches of two activities overlap, meaning that some combinations of environmental factors provide suitable habitats for both the activities, competition or conflict may arise. An example of this in the central hardwoods region is motorized versus nonmotorized travel. As previously mentioned, use of ATV's is increasing in a variety of settings, creating conflict with other activities once dominant in these settings. Competition from motorized use may force activities such as hiking out of areas that have become popular for ATV users. This may be viewed as part of a process of succession, leading towards a high-density "climax" recreational community that includes only activities that are tolerant of noise and high use levels. Management can intervene to halt this successional process and maintain some environments for noise- and crowd-intolerant activities by imposing regulations, limiting use, and closing roads. One question for research in this area is to determine the "limits of acceptable change," that is, what signs of human use can be tolerated in primitive areas before these areas become unsuitable for wilderness-oriented activities (Stankey et al. 1985).

## LANDSCAPE ECOLOGY

Another area of ecology that may be applicable to recreation in central hardwoods is landscape ecology (Forman and Godron, 1986). This field is concerned with the spatial structure and function of landscapes, particulary in regard to the movement of organisms, energy, and substances between ecosystems. Outdoor recreation frequently involves movement, both as travel to reach a suitable recreation site and as part of the recreation activity on the site. The emerging principles of landscape ecology may therefore help us to understand the spatial aspects of recreation behavior. For example, landscape ecology concepts may be useful in determining the size and shape of habitat necessary to maintain certain recreation activities, and in understanding the effect of landscape heterogeneity on the diversity and spatial distribution of activities in an area.

One aspect of central hardwood landscapes is the ownership pattern within the forest. National Forests in this region are a patchwork of private and public land. This restricts opportunities for activities, such as wilderness backpacking, that require unrestrained movement through large areas isolated from human influence. Many of the landscape principles being developed for managing wildlife species may also apply to recreation activities, such as using corridors to link patches of habitat and provide a greater continuous range for movement.

Larger scale landscape issues are also important for visual management in central hardwoods. Over a period of years, even-age management creates a patchwork landscape of different age stands. How is this landscape perceived by people traveling through it? In comparing the esthetic impacts of alternative timber management approaches (e.g. even- and uneven-age systems), it will be important to consider not only perceptions of individual stands, but also perceptions of the larger scale landscapes that are composed of those stands.

## CONCLUSION

In this paper I have suggested some ways that recreation research could use concepts of ecology to address problems in the recreational use of central hardwood forest ecosystems. Ecology may provide a theoretical framework for tying together disparate areas of recreation research. Developing an ecological viewpoint towards human users in the forest environment may also help to bridge the disciplinary gap between biologists and recreation researchers and facilitate integrated research and management of central hardwood forests.

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# IMPLEMENTING GROUP SELECTION IN APPALACHIAN HARDWOODS USING ECONOMIC GUIDELINES[1]

Britt A. Boucher and Otis F. Hall[2]

Abstract.--A method is described for designing plans for group selection harvests in Appalachian hardwoods. Product market values, tree quality, tree growth potential, and local logging costs are used to develop the most profitable operation. In this way, forest stands may be located where this regeneration prescription can be practically applied. A field computer is demonstrated as a means of generating marking guides and tallying cut and leave data.

## INTRODUCTION

For the past decade there has been contention between the public and the administration of the national forests in the Appalachians over the systems of silviculture and harvest cutting to be used. Primarily the contention has stemmed from the public objections on aesthetic grounds to clearcutting of large areas. The Forest Service has supported this practice on the silvicultural basis that it leads to regeneration of the more shade-intolerant species which are of higher value.

More recently, the contention has been brought into sharp focus by the requirements of the National Forest Management Act that each national forest must prepare every ten to fifteen years a management plan, and that this planning process must include a formal process of public review, which can include the appeal to higher administrative levels. This entire process on the Jefferson National Forest (JNF) has led to the provision in the finally approved management plan that about 24,000 acres will receive uneven-aged management (Alcock 1985). On this area, "group selection" will be the regeneration method used. This decision was made to see if the small groups, 2 acres or less in area, on which most or all the trees will be harvested, will better achieve the plan's visual and wildlife management goals, while being large enough to regenerate and grow the more commercially desirable, light-demanding species.

Although group selection has been a method of regeneration recognized in forestry literature for many years, its application in regular commercial forest operations is practically absent. Its implementation and regulation raise many questions such as:

How can the inventories be conducted to properly regulate the volume for sustained yield?
How will the groups be initially located and marked for harvest or treatment?
What impact will this type of harvest have on stumpage values, logging costs, and on costs of timber sale administration to the Forest Service?

This is a report of a joint study by the Jefferson National Forest and Virginia Tech School of Forestry and Wildlife Resources to develop and test techniques of inventory and management decisions that can be used to implement group selection. It is recognized that techniques developed during the study, even though very usable in facilitating the initiation of the first marking and harvesting activity, will be insufficient to judge how successful this method will be in regenerating desirable intolerant species. It will take much longer term studies to determine that.

The approach of this project is to recognize first that all areas of the Forest are not equally suitable to such management, and in some areas its implementation at this time is not

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silviculturally and economically feasible. Therefore, the need exists for a method of locating groups in such a way as to make any proposed sale area most favorable to the subsequent growth and regeneration of the more valuable species, while at the same time yielding an adequate profit to a logging contractor. Aesthetic appeal, wildlife encouragement, and hydrologic protection must be considered simultaneously. If analysis shows that the sale cannot be made profitably, it can be dropped or modified. In this way, the uneven-aged management program will get the most realistic test, and the public will have assurance of continued implementation, perhaps with appropriate modifications.

Although the viewpoint in this project is primarily that of the Forest Service managing national forest lands, it is believed that the methods developed would be equally applicable on other public or private hardwood lands in the same region.

In the course of the project, we have monitored areas on the Jefferson National Forest where group selection timber sales are proposed or being carried out. The Taylor Branch Timber Sale on the New Castle Ranger District was the first group selection operation sold. It was very carefully designed by the Forest Service staff without using the method described here. We have visited the site a number of times after it was marked and while logging was going on. Based on several interviews held with the logging contractor, a reasonable profit was realized from the operation, and no unusual operational problems were encountered.

## DISCUSSION

Although group selection appears in forestry texts as far back as the "First Book of Forestry" by Filbert Roth in 1902, recent discussion among the professionals suggests there are still many differences of opinion regarding its definition, biological effects, regulation, and economic feasibility. Regarding the above questions, no absolute assessments are offered here to fuel the debate, only comments as the topics apply to this project.

The most basic decision in any uneven-aged system is "Should we cut this tree or not?" In group selection, the emphasis must be on the predominate characteristics of the entire group of trees (Marquis 1978). A system is needed which locates and selects the best groups of trees for the regeneration harvest. Landowner objectives, both immediate and future, along with the answers from the above questions will dictate which trees are best for removal. To make the basic decision for group selection, the character of these "best groups" must first be defined.

Once it is established which kinds of groups are the ones to leave or cut, a method for locating these groups in the field must be designed to enable the forester to implement the objectives of the landowner. It is the problem of developing a method that this paper confronts. Landowner objectives vary, as do the opinions of foresters, on what the forest should look like after a harvest operation. What diameter distribution should it have? What should be the maximum tree size and the residual basal area? The initial step in solving the "group selection problem" might seem be to answering these questions, but this is a formidable task in itself.

This project proposes a method to implement group selection, or modifications of it, that will assist the forester in assembling the information to perform the marking for harvest so that the objectives of the landowner, whatever they may be, will be satisfied (restricted of course by the ecology of the forest). This information and its manipulation is the decision support system that will aid the forester in making the "basic decision" by providing information on a single tree, a group of trees, and the area surrounding the trees, in the field where the decision must be made. Therefore, identifying the variables that would enable the marker to make decisions on a range of landowner objectives was the first step of this project. Following is a discussion of the traditional decision variables and the additional ones proposed.

### Traditional Views on Tree Grouping and Selection

"Group selection is a regeneration method in the uneven-aged silvicultural system... but you define a group" (D.W. Smith, personal communication). Deriving from a dictionary definition, a "group" in this context is a number of trees to be removed together because of certain similarities, such as species or size. Traditional decision variables used in selecting between cut and leave trees under uneven-aged management, as described in a priority order by Arbogast (1957), are risk, cull, crown form and branching habit, value, crown position, and size.

One widely accepted method of regulation for uneven-aged forests has been the reversed J-shaped curve of diameter distribution addressed by many authors, with stand density and maximum tree size as other controlling factors (Leak 1985, Smith and Lamson 1982, Marquis 1978, Roach 1974). Economic factors (Cayen and Hall 1987) and financial maturity (Trimble et. al. 1974), have also been introduced. Therefore, tree grade, tree diameter, stand density, and financial maturity are used as decision variables.

### Bringing in Economic Factors and Landowner Objectives

Tree value as it reflects quality, and value growth percent, the tree's rate of value increase, are also variables to be used when selecting trees to cut and leave. Because stumpage value is a residual representing the dif-

ference between the selling price of the final product and the total operating costs and profits in harvesting the timber and converting it into the final product (Kingsley 1986, Zaremba, 1963), it serves as a measure of tree value.

Tree value growth percent (VG%) allows trees to be compared to one another as capital investments. There is a limited amount of growing space for each "investment" and prudent investors would do well to have their portfolio stocked with the investments returning the higher rates. Exact value growth percents are difficult to determine, but relative ones are all that is required to make decisions between trees.

Not only timber value, but all of the land owner's objectives, however diverse, must be considered in the decision process. It must be remembered that in many cases group selection will be practiced because there are several objectives. Generally, we want decisions to bring about the maximum net benefits received from the forest (of course, limited by the allowable area to harvest). In addition to immediate profit, other objectives might include:

- Positive financial benefit for dollars invested
- Increase in the forest's rate of return
- Increased forest access
- Enhancement of wildlife habitat
- Minimum impact on the environment
- Minimum visual impact

The combination of all the biological, economic and regulatory objectives must be included in that most basic decision, "Should we cut this tree or not?"

Combining the list of current objectives with the traditional ideas for making cut/leave decisions for a single tree, and then a group of trees, requires a vast amount of information to be related by the deciding forester. Thus, to implement group selection, it is necessary to build this knowledge into a sort of decision support system, incorporated into several computer programs to be held in a field computer.

## The Suggested Method for Group Selection Management Introduction

The method proposed demands no new techniques regarding tree mensuration and only requires simple observations of the area surrounding the place (point) where the forester is standing in the field. The way the information is stored, processed, and utilized, however, is unique. First a brief summary of the method is described which includes a clarification of several terms. Following that is a more detailed presentation of the proposed method.

A flow chart, figure 1, helps to link the stages of implementation. Notice that the left side of the chart references office work, the right side field work.

### Method: Summary

The traditional method of marking for a regeneration harvest is to first review any office records of the stand's history. Then, the forester goes to the field to collect current information. After returning to the office to analyze the information gathered and plan the marking operation, he/she returns to the field with marking rules in hand to mark the trees for harvest. When enough volume is marked or the entire area covered, the forester returns to the office and prepares the sale prospectus. After testing many departures from this traditional sequence, we chose it as the one to follow.

Although the basic method is similar, the information provided for decision making in the field is a step up from traditional. The data is gathered from point samples. The first pass, the reconnaissance cruise, is for the purposes of: obtaining tree data, collecting area information on site quality, regeneration, and wildlife, and location of skid roads. The reconnaissance cruise is laid out on a wide spaced grid of sample points (6X6 chain).

The information gathered is summarized in the office and a determination made as to whether or not a harvest is possible based on current volume and market prices. Given a positive decision, the forester returns to the field for the a marking/cruise. Again, the forester takes point samples using a closer spacing (3X3 chain grid) to collect information for decision making. Cruise data is tallied on the field computer, and information is provided as a decision aid to determine whether or not this "point" should be considered for harvest. Once the required marked volume is obtained, or the end of the tract reached, the forester returns to the office to prepare the sale prospectus and store the inventory information for future management.

Clarification of terms is required here. A point sample is used to sample an area that is being considered for harvest. A 3X3 chain grid for the marking/cruise is chosen because it approximates a point in every acre (this is not a fixed requirement). The trees selected by the prism, around the center of the acre, represent this acre as a group in the decision of whether this should be a group to harvest or to leave. If the point is selected for harvest, the trees included in the sample, and suitable trees surrounding the point are marked for removal or treatment. Therefore, in this discussion "group" is defined as two or more trees marked for removal or treatment in a contiguous area, with a maximum of as many trees as can be found on that one acre (or the area represented by the selected grid size). The point then, initially represents a group, although the final marked group can include part of, all, or more trees than the "point". Also, several points could be combined to form any shape, and any practical size group, or harvested area. The size and

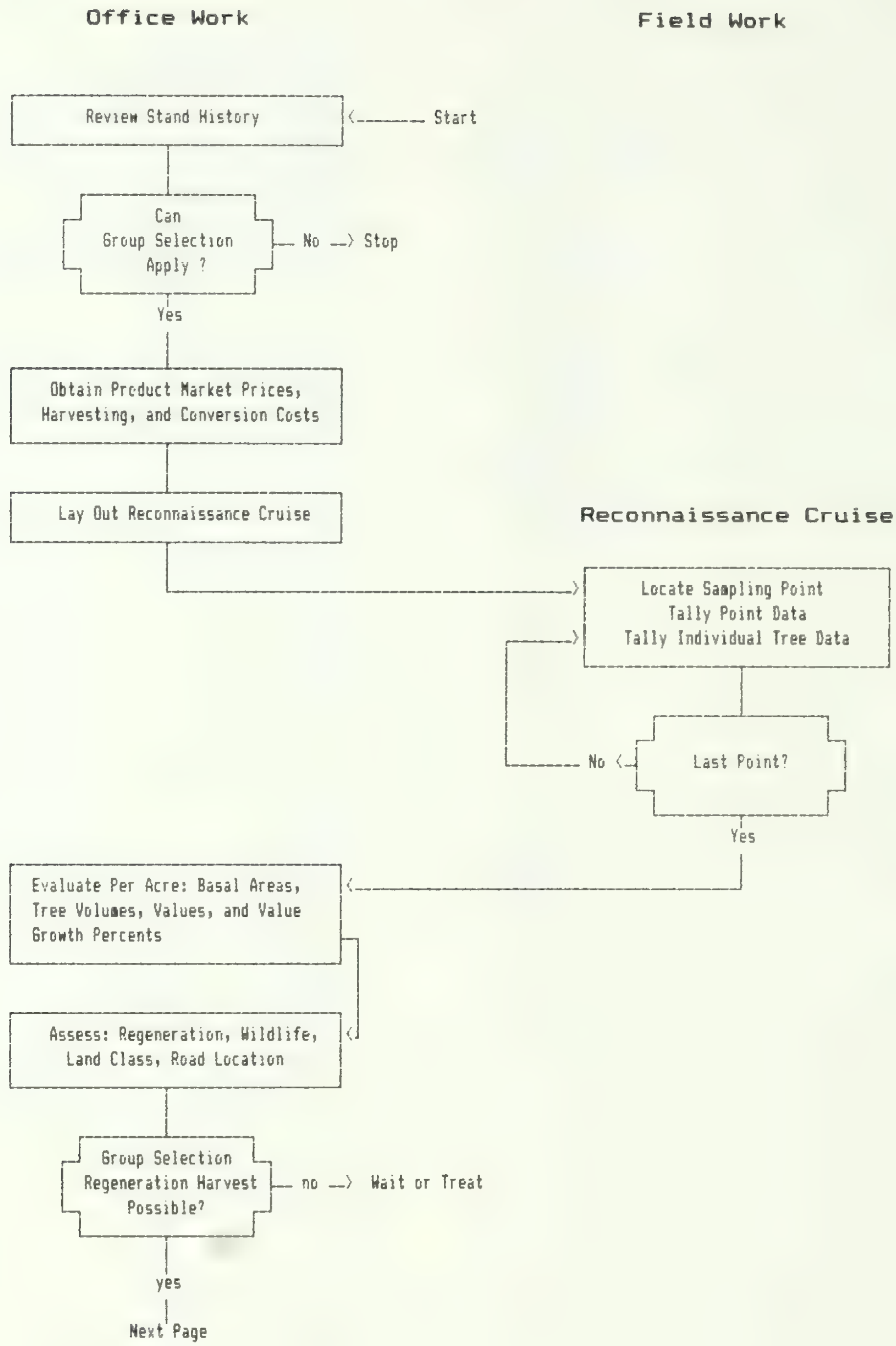


Figure 1.--Flow Chart For Group Selection Implementation

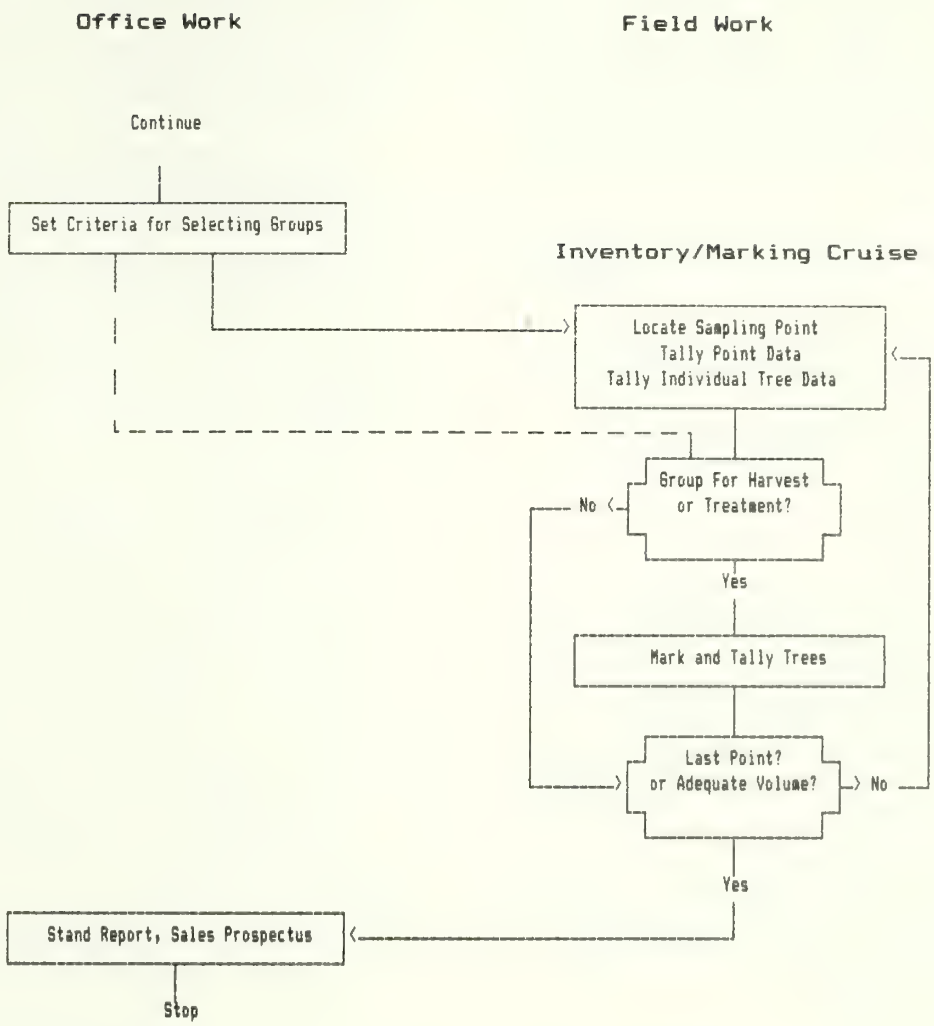


**Figure 1.1--Flow Chart For Group Selection Implementation**

shape is restricted by the silvicultural judgment of the forester and the objectives of the landowner.

This is not to say that the group will be easily identifiable or its boundaries distinct. Trees in the group, yet not ideal for removal based on their potential to become valuable crop valuable crop trees may have to be marked for harvest. This is because they will most likely be damaged or destroyed in logging and/or leaving them will result in an insufficient opening for regeneration. The alternative would be to move the group boundary to exclude them.

Method: Detailed

More detail of the cruise and decision method is now provided. First, an examination is made of the maps and other records on the tract for information on the stand's history and current condition, site index, soils, wildlife, land use class, existing roads, etc.. If the group selection regeneration method still seems suitable for this stand a reconnaissance is planned. A field map is made of the area with sampling points located on a 6x6 chain square grid.

Additionally in the office are noted factors for the entire area affecting logging cost, such

as estimated average skidding distance, existing or future landing locations, hauling distances, and special equipment needed. These factors are used to estimate logging costs per thousand board feet of timber harvested. Logging cost is one of the most variable costs associated with tree value. However, reasonable approximations are all that is required in order to compare one "point" (representing a group) to another. (Logging costs for group selection are currently under study at Virginia Polytechnic and State University.)

To prepare for the computations performed in the field computer the following information is collected and downloaded to the field computer:

1. Lumber prices for the species, or species groups, to be inventoried, from the Hardwood Market Report, Appalachian Hardwoods.
2. Sawmilling costs for typical operations.
3. Pulpwood or firewood stumpage prices from Timbermart South or local mills if these are potential products.

Reconnaissance Cruise

After going to the field, the forester carries out a point cruise with a 20BAF prism (factor optional, based on timber type), varying from the grid to assure that several points are located in each strata as determined by topographic inspection. The reconnaissance is the time for skid road inspection or location and for noting any physical barriers that will preclude logging of certain areas. At each point, data on the following are entered in the field computer:

1. Land Classification Code, Appendix I: Includes site index (low, medium, high) for standard forest land based on general inspection or topography
2. Wildlife Class Code
3. Regeneration; Upper/Lower
4. Age Class Code
5. For each tree counted:
   a. Species
   b. Diameter at breast height
   c. Merchantable height
   d. Estimate of possible merchantable height growth
   e. Tree Grade (Hanks 1976)
   f. Estimate of possible grade increase

Office Data Summary

Upon return to the office, the cruise tally and point values are transferred to the office computer. The tree volumes, values, and value growth percents have been calculated and totaled by point in the field computer providing a listing by point of the reconnaissance cruise. Land class, wildlife class, regeneration, and age class codes are also transferred to the office computer for evaluation. A point-by-point listing giving the status of each tree, as well as point per-acre totals and tract averages are available. Examples of two point lists are shown in table 1.

Overall Stand Assessment and Selection Criteria.

From the point summaries and the overall statistics the forester is in a position to make a more accurate determination of whether or not group selection is feasible on this area. If it is feasible, what criteria should be used to select the groups to mark for harvest?

In selecting between points to mark for harvest there are many point characteristics to consider. The problem: "If" a forester had a list of the all the point samples from the tract in question, which points would be best to harvest? With multiple-use a goal and both short and long term objectives to satisfy, what variables should be considered as having the highest priority? The variables that have the most influence seem to be land class, wildlife class, regeneration, point value and point value growth percent.

The solution for the problem is a series of rules designed to assist the forester in the field to arrive at a conclusion based on the information given about the point. Such a series has been given many names: a decision tree, a decision support system, or an expert system. The rules have the format of an "if-and-then" statement leading to a treatment recommendation. Two examples follow.

If the land class is standard forest land,
medium site index
and the wildlife class, snag
and the upper regeneration, dogwood
and the age class, small sawtimber
then leave this point to grow

A second example:

If the land class is standard forest land,
medium site index
and the wildlife class, none
and the upper regeneration, oaks and the age class, sawtimber
and the value growth percent is less that the tract average
and the point's value is greater than 80% of all other points
then consider this point for harvest.

The entire decision tree is too large to illustrate and explain within the confines of this paper. It contains 76 rules. Rules can be easily modified, or added to accomplish an individual landowner's goals or management preferences. An expert system is never considered finished and is in a constant state of evolution as new demands and objectives are placed upon it.

The treatment recommendations are only provided as aids to help the forester make the selection decisions between points; they are not requirements. The forester must combine this recommendation with other knowledge and observations about the area to arrive at a final decision.

### Table 1.--Example of Data Collected and Information Provided For Two Points

Explanation of abbreviations is found in Appendix II

Treatment Recommended; leave

Land Class Code; standard forest land, medium site index
Wildlife Class Code; large active snag present
Regeneration Upper; dogwood
Regeneration Lower; none
Age Class; small sawtimber

| Recorded Field Data | | | | | | Single Tree | | | Per Acre Values; Point Sample | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spp | Dbh | Ht | HI | GT | GI | CF | BF | $/T | CF | BF | $/Ac | $/Ac10 | VG% |
| NRO | 11 | 1 | 1 | 3 | 0 | | 40 | 8 | | 1209 | 231 | 372 | 4.86 |
| HIC | 12 | 2 | 1 | 3 | 1 | | 105 | 7 | | 2662 | 166 | 318 | 6.72 |
| HIC | 10 | 1 | 0 | 3 | 0 | | 29 | .1 | | 1078 | 3 | 57 | 36.17 |
| SUM | 3 | 0 | 0 | 0 | 0 | | | | | | | | |
| NRO | 16 | 1 | 0 | 3 | 1 | | 119 | 34 | | 1701 | 482 | 793 | 5.11 |
| YEP | 12 | 1.5 | 1 | 2 | 0 | | 77 | 8 | | 1951 | 200 | 242 | 1.92 |
| Totals (weighted avg. for VG%) | | | | | | | | | | 8601 | 1082 | 1782 | 4.97 |

Treatment Recommended; mark for harvest

Land Class Code; standard forest land, medium site index
Wildlife Class Code; none
Regeneration, Upper; oaks
Regeneration, Lower; oaks
Age Class; sawtimber

| Recorded Field Data | | | | | | Single Tree | | | Per Acre Values; Point Sample | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spp | Dbh | Ht | HI | GT | GI | CF | BF | $/T | CF | BF | $/Ac | $/Ac10 | VG% |
| WHO | 16 | 2 | 0 | 2 | 0 | | 161 | 36 | | 2309 | 516 | 623 | 1.90 |
| CHO | 14 | 9 | 1 | 4 | 0 | 27 | | 1 | 500 | | 25 | 28 | 1.23 |
| HIC | 11 | 1 | 0 | 3 | 0 | | 39 | 1 | | 1170 | 37 | 78 | 7.65 |
| CHO | 22 | 1.5 | 0 | 2 | 0 | | 260 | 54 | | 1972 | 410 | 423 | 0.29 |
| WHO | 18 | 2 | 0 | 1 | 0 | | 205 | 60 | | 2315 | 677 | 791 | 1.56 |
| Totals | | | | | | | | | 500 | 7766 | 1665 | 1943 | 1.48 |

Part of the decision tree addresses the question of regulation. An estimate of harvest age and cutting cycle will be sufficient to guide the amount of volume or area that can be removed each cutting cycle. If 100 years are required to grow a tree to harvest size and a cutting cycle of 10 years selected, then approximately 10% of the area should be removed each cycle. An exact determination of this factor is not essential in the early stages of implementing group selection.

Many of the stands being considered for uneven-aged management are currently even-aged or two-aged stands making volume control difficult. Although not in line with traditional methods of uneven-aged management, area control is suggested as a feasible regulation method. Volume growth checks should also be made, and monitoring the diameter distribution of the stand is also possible.

The rules of the decision tree aid the marker in maintaining regulation in several ways. When entering the stand for the marking operation, statistics from the reconnaissance cruise provide the decision tree with valuable information about the stand, namely, the distribution parameters of values and value growth percents (VG%) of the points. Now, in the field for the marking operation and standing on the point in question, a comparison can be made with all other points previously sampled. Assuming the values and value growth percents are normally distributed, an estimate of where this point is on the distribution can be made. For example: if our primary objective is to increase the value growth percent of the stand, then it would be best to select those points for harvest that have the lowest percents. If our goal is to remove 10% of the stand, then any point having a VG% lower than the cutoff value which represents the lower 10% of the distribution, would be recommended for harvest.

Value works in a similar way, except one would be marking those points that fell above the upper cutoff point on the distribution. Combining the two objectives creates problems and the answers are not clear cut. Field testing of this regulation method is not complete. However, bench tests indicate that it will at least provide a helpful rule when deciding between points to harvest. Simpler methods are also included in the decision tree such as the volume cruised/volume marked ratio. Also by knowing the number of points sampled, and the number points marked for harvest, a running approximation is provided of the percent of the stand that has been marked.

Cruise/Marking

Then returning to the field, the forester re-cruises the sale area on a 3X3 chain grid, using a 20 BAF prism. At each point, the same information as in the reconnaissance cruise is collected and the tally entered into the field computer. Often the point to be sampled has little chance of becoming a harvested or treated point. Such a case would exist if the area was harvested within the last two cutting cycles, or, if the area contained but one hemlock tree and was near a spring surrounded by rhododendrons. The data input portion of the program recognizes points that are inefficient to continue sampling and stops after such cases are recognized.

If the point being sampled is a possible harvest point the information about each tree found in the sample is tallied. The tree's volume, value, and value growth percent, is calculated and displayed. The point totals and averages are calculated and a treatment is recommended.

The cut/leave decision is made at this time, based on the marker's judgment and the treatment recommended by the decision model. If a leave decision is made, the sample point data are added to the cumulative leave file, providing a steadily improving estimate of the structure of the stand. If a cut decision is made, marking begins. Trees surrounding the sampling point with characteristics that make them desirable for harvest are marked until the appropriate group size is attained. When the group marking is finished, its outline is sketched on the field map, and the tally is added to the cumulative cut file being carried in the computer. This file includes cumulative volume and value figures for judging the adequacy of the marked timber for a commercially feasible operation.

As the flow chart indicates, it may be possible in some locations to mark for intermediate improvement or thinning treatments at some points. If such an operation is feasible, a tally of the points to treat, or the number of trees to treat, is made.

Single tree data can be entered into the computer to check volume, value, and VG%. During skid road location trees to be removed can be entered into the cumulative cut file. Additionally single trees located beside skid roads or in proximity to a harvested group might be selected for harvest; these also can be entered and added to the harvest file. When the entire tract has been covered, or the desired volume or area to harvest obtained, the marking cruise is terminated.

Return to Office

The forester returns to the office and the files of marked trees and inventory information are transferred from the field computer into the office computer. Possible summaries include:

1. The cumulative leave file providing a record for use at the next cutting cycle. By comparing this file to the total inventory file, which includes the harvested points, a measure is obtained of the effect on the productivity potential of the tract.

2. The tally of points showing the percent of the tract that falls in each land class, wildlife class, and age class.
3. The regeneration of the tract in percent by species group.
4. Listing of points, or marked trees, to receive various treatments.
5. The cumulative marking file, used for the preparation of the timber sale prospectus.

## A Comment on Computers

The entire procedure is built upon software developed by the one of the authors, for use on the IBM Personal Computer for office work and on the Hewlett Packard HP-71 Computer for field use. The field computer was specially configured by Oregon Digital with a maximum of 357K memory and a special case to withstand rugged use. It is felt to be an illustration of the way the portable computer can assist in making available to the field forester an enormously expanded volume of essential information to guide the marking decision.

## Concluding Remarks

Any experienced forester is going to ask if such a seemingly complex procedure is really practical. Yet, except for tree grade and possibilities of increase, all the other information collected is normally tallied for a presale inventory. The information is just calculated differently and made available while the forester is still in the field.

It is believed that following such a procedure can be excellent training and that with experience the procedure will be streamlined. In some applications certain details may be omitted. But, if all the landowner's objectives are to be considered, a procedure similar to this will need to be followed until it is broadly established and accepted under what circumstances uneven-aged management and group selection can be successfully carried out. In many cases, provision for options is made without recommending the decision to give latitude to those owning and managing the forest.

Until, in the mind of the decision maker, the tree, with the local costs of removal considered, is associated with its market value, both present and future, and until the marking decision of that tree along with the other trees of the group is based on all of the landowners objectives, less than satisfactory management will occur.

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## Appendix I: Classification Codes

Land Class Codes

Non-Forest Land; field, rhododendron, young forest.
Utility; transmission lines, gas, oil, railroad.
Road Buffer; width depending upon road class/use.
Recreation Area, Special use: trail buffer, cultural.
Wildlife Area; designated clearing, special habitat
Spring, Seep, Wetlands
Water Buffer; width depending upon size or use.
Hardwood/Pine Low; SI 50 oak, 9-13" DBH is mature.
Hardwood/Pine Normal & White Pine; SI 60, 11-17" DBH oak.
Cove & Upland Hardwood; SI 70+ oak, 14-30" DBH.

Wildlife Class Codes

None
Insect, Pathogen
Beaver sign
Cliff System, Rock out-crop.
Water Area; trout stream, wood duck habitat, watering hole.
Bedding area, Den, Squirrel nest, Caves, Sink holes, Drumming logs.
Snags, Wolf Tree, High mast producer, Large pines >30" Dbh, Den tree.
Feeding area; orchards, old home sites, grass, rare forage, grape arbor, alder thickets.
Red-Cockaded, Piliated, Hawk nest, Heronry, Endangered spp.

Regeneration Codes: Upper/Lower

None
Grapevines (Greater than 50 stems per acre / Grass
Rhododendrons / Ferns
Dogwood, Sourwood, Sassafras, Striped Maple, Blackgum.
Maples, Beech, Birch, Black locust.
Yellow-Poplar, Basswood.
Pines; Pitch, Virginia, Table Mountain.
Pines; White, Hemlock.
Desirable Hardwoods: Ash, Walnut, Hickories.
Oaks; red and white.

Age Class Codes

Saplings; 0-5 inches in diameter at breast height.
Poles; 6-9 inches DBH.
Small Sawtimber; 10-13 inches DBH.
Sawtimber; 14+ inches DBH.

## Appendix II: Explanations of Abbreviations Found in Table 2

Spp - Species

Dbh - Diameter breast height

Ht - Merchantable height in number of 16 foot logs for tree grades 1-3, and number of 5 ft. sticks for grade 4 trees and trees less than 10 inches in Dbh.

HI - Possibility of merchantable height increasing in the next 10 years; 0= no possibility, 1= possibility of increasing. The increase added depends upon site index, dbh, and height of the tree.

GT - Tree Grade. Forest Service grades 1,2,3 (Hanks 1971). Grade 4 is pulpwood and trees less than 10 inches dbh.

GI - Possibility of tree grade increasing with growth due only to the overgrowth of a present minor defect. 0= no possibility. 1= possibility of grade increasing in 10 years. Note; a grade increase will occur automatically if the tree's diameter increases enough to place it in the next higher grade even if GI=0.

CF - Cubic feet, BF - Board feet

$/T - Dollars per tree - For sawtimber (BF trees), this is a stumpage value based on the board feet of dry lumber produced, as estimated by Hank's (1976) equations for each graded tree, multiplied by the graded dry lumber prices from the Hardwood Market Report, minus logging, conversion costs and profits. Trees with CF volume are valued by: the estimated cubic foot volume multiplied by the price reported in Timber Mart South, or from local mills. The price of firewood, if higher and a realistic alternative, would replace the CF price.

Per Acre Values; CF, BF, and $/Ac are individual tree values multiplied by the tree's per acre conversion factor (basal area factor/basal area of the tree).

$/Ac10- Estimated value per acre in 10 years.

VG% - Value Growth Percent; calculated by: $i = [(Vn/Vo)^{(1/n)}] - 1$ and $VG\% = 100(i)$ Where; $n$ is the number of years, 10, $Vo$ is the tree's value in the present day, and $Vn$ is the value $n$ years in the future. Analysis has shown that the most important factors in determining VG% (in order of importance) are grade, height, and diameter increases. Grade and height are direct field estimates. Diameter growth can be estimated from any one of the growing number of growth functions for the hardwood region. Due to its simplicity, Mawson's (1982) formula: $\ln DG = \ln 1.65 - 2.64 / Dbh$ where DG = 10 year diameter growth in inches, is used here for testing of the method. The VG% in the "total" line is not a total but an average of the tree's VG% weighted by value.

HISTORICAL EVIDENCE OF FOREST COMPOSITION

IN THE BLUEGRASS REGION OF KENTUCKY[1]

Julian J.N. Campbell[2]

Abstract.-- This study summarizes early records of forests in the Bluegrass, a fertile region that is now largely agricultural. More fertile soils had much sugar (and black) maple, walnuts (mostly black), hickories (mostly bitternut), ashes (mostly white and blue), oaks (mostly bur and yellow) and other species. The abundance of successional species like black walnut is attributable to prior disturbance involving Indians and large herbivores. Trees marking property boundaries included less of the successional species, which may have been concentrated near the more disturbed centers of settlements. Less fertile soils generally had oak-hickory forest dominated by white oak, or beech forest with some yellow poplar, but there was much mixture with species of more fertile soils. Beech was dominant in some of the western and northern areas, where soils have more loess content. Hypotheses are advanced to explain the region's unusual composition and its historical changes, especially in the blue ash-oak woodland-pastures.

## INTRODUCTION

The Bluegrass Region is the area in north-central Kentucky that is underlain by Ordovician bedrock, mostly limestones and calcareous shales. It is now predominantly agricultural, and the remaining woodland receives little management for timber production. However, there is much interest in the original forests here (Braun 1950), and the potential role for forestry in the region (Kingsley & Powell 1978). Because of its high soil fertility, the Bluegrass was one of the first regions west of the Appalachian Mountains to be settled, during 1775-1800. This led to the rapid, early destruction, or at least great modification, of most original vegetation. It is difficult to estimate the presettlement conditions from what little remains. Braun called the Inner Bluegrass, which is particularly fertile and agriculturally developed, "the most anomalous of all vegetation areas of eastern United States." In the Eden Shale Belt and the Outer Bluegrass, somewhat more forest remains, but virtually no old growth. Braun included the whole region in her Western Mesophytic Region, which she generally defined as a mosaic of mesophytic forest and oak-hickory forest. Kuchler (1964) mapped the potential natural vegetation of the area as oak-hickory forest. However, within less disturbed areas today, this type is only prevalent in the Eden Shale Belt (Bryant 1981). Data adequate for an accurate mapping of this region are not currently available in the scientific literature. The purpose of this paper is to summarize some important historical evidence concerning the composition of the original forests, and to discuss the ecological implications of this evidence.

Considerable attention has been given to the degree of openness in the presettlement vegetation (Davidson 1950, Campbell 1980, Bryant et al. 1980, Bryant 1983). Old accounts indicate that the region was generally "well timbered" and that there were no treeless areas like the prairies or barrens further west. However, some areas on "rich" (fertile) soils were more thinly wooded, with canebrakes, successional forest and perhaps savanna-woodland (Bryant et al. 1980). Exactly what maintained these more open areas is unknown. They may have been influenced by Indians, using fire, and they were much used by buffalo, elk and deer; periodic droughts may also have been a factor (Campbell et al. 1988, and unpublished). Some frequent trees at the time of settlement are indicative of successional conditions, based on general knowledge of their ecology (Campbell 1980). These included black walnut, cherry, honey and black locust. The relative abundance of these species, and hence the extent of successional conditions, can be

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estimated from data presented in this paper. Modern woodland-pasture areas that resemble mid-western savanna-woodland are dominated by blue ash and oaks, which are relatively drought-tolerant and perhaps fire-tolerant. However, if grazing and mowing of these areas ceases, they are currently invaded by more mesic species. The original status of these woodland-pastures is not well understood.

The division of this region into different geological and edaphic sections is crucial for interpretation of patterns in forest composition (fig. 1; see also McDowell et al. 1981, U.S.D.A. 1974 and county soil surveys). The Inner Bluegrass lies on Middle Ordovician limestones, most of which are phosphatic; it has highly fertile hapludalf and paleudult soils. Outside the Inner Bluegrass, the Eden Shale Belt lies mostly on Upper Ordovician calcareous shales (the Clays Ferry Formation) and the Garrard Siltstone; it generally has less fertile hapludalf soils. In the east, typical Eden Shale soils are less extensive and there is generally a direct transition from Inner to Outer Bluegrass soils. The Outer Bluegrass lies mostly on Upper Ordovician limestones and calcareous shales; in addition, there are some overlying loess deposits in the west (Barnhisel et al. 1971), and pre-Wisconsin glacial deposits in the north. Outer Bluegrass soils are generally hapludalfs, intermediate in fertility between the Inner Bluegrass and the Eden Shale Belt. Surrounding most of the Bluegrass Region in Kentucky is a narrow zone of Silurian bedrock, including some dolomitic limestone with natural "cedar glades", and the Knobs Region, which lies mostly on non-calcareous shale of Devonian and Mississippian age and on Mississippian limestone. Further to the south and west is the Mississipian Plateau, which is mostly calcareous, including the former "Big Barrens" region. Further to the east is the Appalachian Plateau, which lies mostly on non-calcareous Pennsylvanian rocks.

## NOTES ON COMMON NAMES

Some preliminary interpretation of the common names used in early sources is needed. Many names can be reliably attributed to a single species, especially in genera that have only one species present. However, some genera with several species present problems.

Acer (maple). "Sugar tree", and "sugar maple" in later sources, refer to A. saccharum (sensu lato), including var. nigrum, which is frequent on the most moist and fertile soils (Campbell 1980). The few plain "maple" references in early sources are assumed to be A. saccharinum, which is restricted to larger watercourses, or A. rubrum, which rarely occurs in old river channels (Campbell 1980).

Aesculus (buckeye). A. glabra is not distinguished from A. octandra in most sources, but Rafinesque (1819) and Short (1828) indicated that A. glabra was much more abundant. Today A. octandra is also much less common, being restricted to the eastern transition and some areas near the larger rivers.

Carya (hickory). Species are rarely separated in early sources, and where they are the names are not reliably identifiable (white, black, pignut, bitternut, shellbark, scalybark). Short (1828) noted that "C. porcina" ("pignut") was the most common species on more fertile soil near Lexington, but his description of its leaves suggests C. cordiformis. A few other notes (Short 1828, Owen 1857, Linney 1882-87) indicate that, among the two shagbarks, C. laciniosa was typical of more fertile soils than C. ovata. In modern forests, C. cordiformis and C. laciniosa are typical of more fertile soils; C. ovata, C. glabra and, rarely, C. tomentosa are typical of less fertile soils (Campbell 1980).

Celtis (hackberry). C. occidentalis is not distinguished from C. tenuifolia, which was probably infrequent, since it is today a small tree largely restricted to dry and wet soil extremes. "Hoopwood" probably refers to C. occidentalis, because it was used in several sources that did not use "hackberry"; also, C. occidentalis has been known locally as "hoopash", e.g., in New England (Dame and Brooks 1972).

Fraxinus (ash). Most sources do not distinguish species. However, according to reliable accounts of "richer" soils, blue ash (F. quadrangularis) about equalled (Short 1828) or exceeded (Owen 1857, Linney 1882-87) white ash (F. americana) in abundance. On fertile soils today, blue ash is more common among older trees, but white ash is much more common in young stands (Campbell 1980, Bryant et al. 1980). Green ash (F. pennsylvanica), a wetland species, is not listed in any source, and it must have been usually included under "white ash". "Black ash" and "hoopash" are frequently listed, but the meaning of these names remains uncertain. Further north, these names generally refer to F. nigra, whose presence in Kentucky has not been confirmed, though it was described here by Short (1828) under the synonym F. sambucifolia.

Juglans (walnut). Most references do not separate species, and may usually refer to J. nigra. However, some deeds specify "white walnut" (J. cinerea), generally with a frequency similar to "black walnut" (J. nigra), and even more in some less fertile areas. Short (1828) noted that J. cinerea was "even more abundant" than J. nigra around Lexington. In contrast, J. cinerea now comprises less than 0.1% of Juglans in the region; its decline here and elsewhere is due to disease (Kuntz & Tisserat 1983).

Quercus (oak). Most sources distinguish the white oak and the black (or red) oak groups, but not the species. In the white oak group, Short (1828) noted that Q. macrocarpa was most abundant on fertile soil near Lexington; Q. muhlenbergii was also frequent; and Q. alba was more typical of less fertile soil. In the black oak group, he described Q. shumardii (under "palustris") as most frequent around Lexington; Q. imbricaria was less common but typical of fertile soil; and Q. velutina was restricted to less fertile soil. He did not list Q. rubra, which today is restricted to more mature forest on steeper slopes. Later

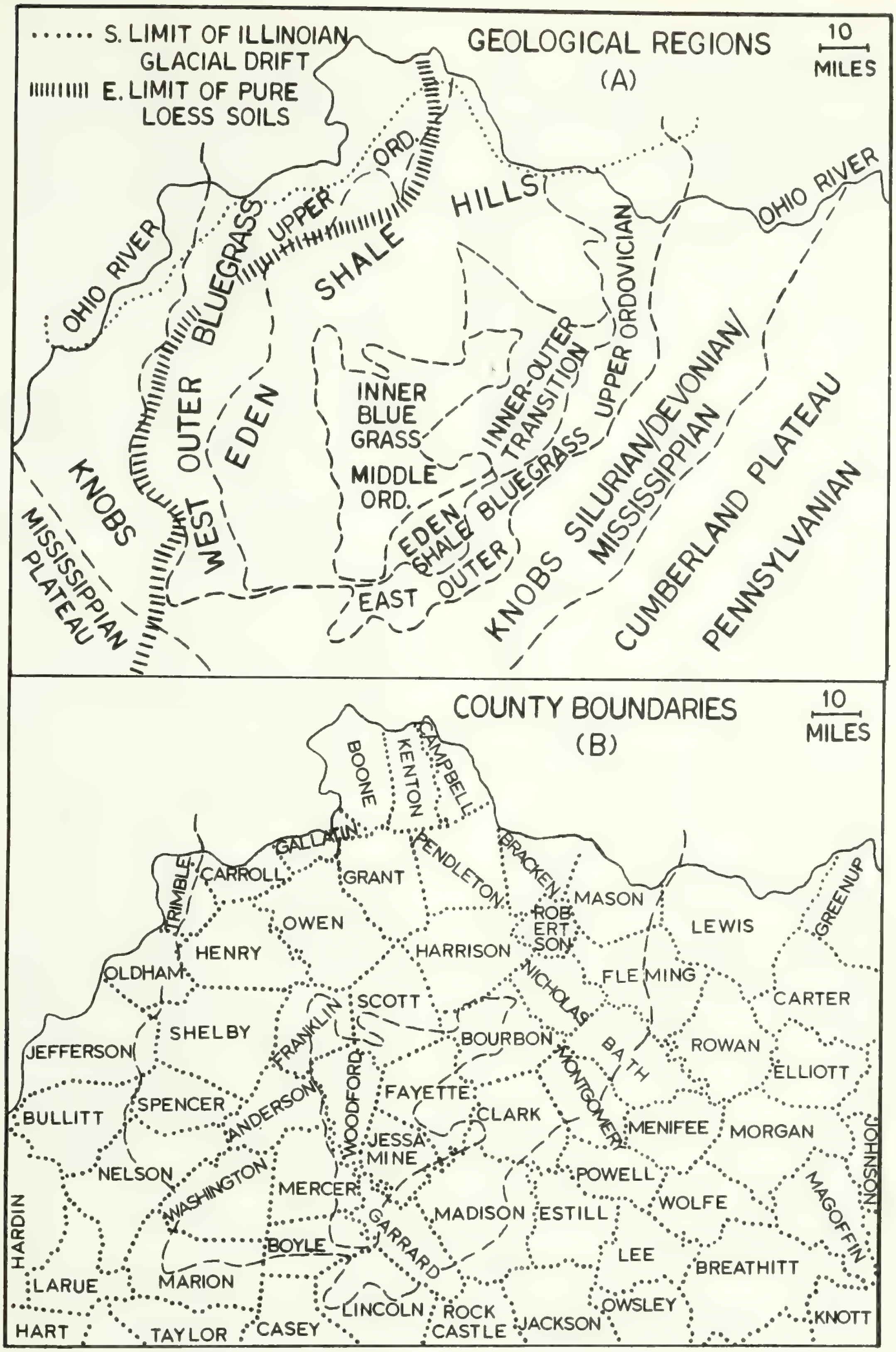


Figure 1.— The Bluegrass Region, showing: (a) subdivisions based on geology (McDowell et al. 1981) and soils (U.S.D.A. 1974); and (b) county boundaries and names.

sources confirm these trends (Owen 1857, Linney 1882-87, Campbell 1980, Bryant 1983).

Tilia (lynn, basswood). T. americana and T. heterophylla are both widespread, but these closely related species were never distinguished in early sources. Their relative abundance remains poorly documented in modern forests.

Ulmus (elm). Most records do not distinguish species. Early deed surveys listed red elm (U. rubra) about twice as often as white elm (U. americana), and F. Michaux (1805) noted a similar difference. However, Short (1828) later noted that U. rubra "has almost disappeared from the forest around Lexington in consequence of its destruction by cattle... [but] In the more accessible situations among the cliffs of Elkhorn and the Kentucky River, it is occasionally met with..." Today, it is much less common than U. americana on more fertile agricultural uplands. Other elms (U. thomasii, U. alata) were reported from rocky sites by Linney (1882-87), and they are rare and restricted to such sites today.

Some confusion may also exist in a few cases at the genus level. Honey locust (Gleditsia triacanthos) and black locust (Robinia pseudoacacia) were not always distinguished. However, it is likely that "locust" by itself generally referred to Robinia, as suggested by Linney's (1882-87) joint listing of common and Latin names. Among the "gums", "blackgum" (Nyssa sylvatica) and "sweetgum" (Liquidambar styraciflua) were often not specified, but the latter was never listed for certain within the Bluegrass Region, and it is much rarer today.

## EARLY LANDSCAPE DESCRIPTIONS

Many pioneers and travellers at the time of settlement supplied comments about the vegetation in journals, letters, books and interviews (L.C. Draper's Manuscripts of the 1840s). In several cases, these people provided lists of trees seen in particular areas. After searching for as many sources as possible, these notes were condensed into an estimate of forest composition (table 1). The percentages in this table are based on the number of times each tree taxon is mentioned in the various sources.

Several sources provide separate lists for areas with "richer" (more fertile) soil and "poorer" (less fertile) soil. The 28 lists for more fertile areas (table 1, combined as column B) indicate that the forest was typically composed of walnuts, sugar maple, ashes, cherry, buckeye, honey locusts, black locust, coffee bean tree, elms, hickories, oaks, mulberry, hackberry, yellow poplar and others (in approximate order of decreasing frequency at the genus level). Walnut and sugar maple were both listed in almost all accounts of more fertile soils, sometimes with notes about the particularly large size of these trees. Walnut was noted as a major component, or at least listed first, about twice as often as sugar maple. Ash, cherry and buckeye were listed in most accounts but indicated as major components only about half as often as sugar maple. Honey and black locust were listed in only half the accounts, but honey locust was noted as a major species as often as sugar maple, and black locust trees were noted as especially large as often as sugar maple. Other trees were listed in no more than half the accounts, though coffee tree was consistently regarded as one of the best indicators of the most fertile soils. Small tree species that were most frequently listed include pawpaw and hawthorns. Short (1828) wrote that "This portion of Kentucky was once the paradise of pawpaws, where immense orchards of large trees were everywhere met with."

Only 12 tree lists referring to less fertile areas were found in early literature. Some of these lists include transitions to the Knobs Region, or to glaciated land in the north. They indicate that the forest was primarily composed of oaks, beech, poplar, sugar maple, ashes, walnut, hickories, black locust, sassafras and others (column A in table 1). While the oaks were generally dominant, beech and poplar were apparently more abundant in areas close to the Ohio River. Sassafras, persimmon, blackgum, sweetgum, chestnut oak and pines were minor species, and their records in table 1 (A and B) are mostly from accounts that include areas peripheral to the Bluegrass Region in its strict definition. They were essentially absent from the more fertile soils. The only small tree species listed more than once was dogwood.

## EARLY DEED SURVEYS

Unlike several states further west or north, there was no systematic land survey in this region during settlement. However, each county courthouse has deed books that incorporate miscellaneous surveys of individual properties dating back to when the county was established, except for a few counties in which such books were destroyed by fire. In the Bluegrass Region most counties began during 1785-1810, though a few peripheral counties did not begin until 1820-1870. The early deed surveys generally noted about 5-20 individual marked trees, with common names, at the corners of property boundaries. For a preliminary summary of these data, the first 100-200 trees in each county's first deed book were used to calculate percentages for different types of tree.

Various uncertainties and biases exist regarding these data. There is no information on the sizes of trees listed in these surveys, though it is likely that trees at least 10-20 cm dbh were used in the great majority of cases. There may also be biases in the types of topographic and edaphic site that were sampled by these deed surveys, since property boundaries were often associated with natural features like ridges and streams. Despite such problems, these data provide an important reference point in attempts to estimate early forest composition.

Table 1. Percentage composition of tree taxa estimated from early accounts and data from the Bluegrass Region*.

| TREE TAXA | ACCOUNTS OF 1750-1850 | | DEED SURVEYS OF 1780-1840 | | | | GEOLOGICAL SURVEY OF OWEN (1857) | | | | GEOLOGICAL SURVEY OF LINNEY (1882-87) | | | | TIMBER REPORT OF BARTON (1919) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
| Acer saccharum (sugar tree, s. maple) | 9.8 | 9.5 | 15.6 | 2.1 | 23.7 | 11.5 | 10.6 | 11.1 | 18.8 | 10.7 | 12.0 | 10.6 | 10.3 | 6.0 | 14.3 | 8.1 | 9.7 | 9.9 |
| Acer negundo (boxelder) | - | 0.8 | 1.6 | 0.6 | 2.0 | 2.6 | - | - | 1.3 | - | - | - | - | - | - | - | - | - |
| Acer saccharinum/rubrum (maple) | - | 1.1 | 0.6 | 1.1 | 0.3 | 0.1 | - | - | - | - | - | - | - | - | (included with above) | | | |
| Aesculus glabra/octandra (buckeye) | 3.7 | 6.0 | 3.4 | 1.4 | 6.8 | 8.5 | 1.1 | 1.6 | 5.0 | 6.6 | - | - | 3.4 | 1.2 | - | + | - | - |
| Asimina triloba (pawpaw) | 1.2 | 5.2 | - | - | + | 0.3 | 1.1 | - | 2.5 | - | - | - | - | - | - | - | - | - |
| Carpinus caroliniana (hornbeam) | - | - | 0.4 | 0.2 | 0.3 | 0.4 | - | - | - | - | - | - | 1.7 | - | - | - | - | - |
| Carya spp. (see text) (hickory) | 6.1 | 4.9 | 8.1 | 11.7 | 11.0 | 18.9 | 9.4 | 14.3 | 11.3 | 6.6 | - | 10.6 | 5.2 | 7.2 | 6.3 | 10.0 | 8.0 | 8.8 |
| Castanea dentata (chestnut) | 2.4 | 0.8 | - | - | - | - | - | - | - | - | - | - | - | - | - | 2.3 | - | + |
| Celtis occidentalis (hackberry) | - | 3.4 | 1.4 | 0.1 | 3.6 | 2.6 | - | 1.6 | 1.3 | 4.9 | - | - | 1.7 | 12.0 | - | + | 1.8 | 2.5 |
| Cercis canadensis (redbud) | 1.2 | 0.8 | 0.4 | 0.1 | + | 0.3 | - | + | 1.3 | 0.8 | 2.0 | - | 1.7 | - | - | - | - | - |
| Cladrastis kentukea (yellowwood) | - | 0.8 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Cornus florida (dogwood) | 2.4 | 0.4 | 2.8 | 12.2 | 1.9 | 2.3 | 1.1 | - | 1.3 | 0.8 | 2.0 | 4.3 | - | - | - | - | - | - |
| Crataegus mollis/crus-g. (thorn, haw) | - | 2.2 | 0.2 | - | 0.8 | 0.6 | - | - | - | 0.8 | - | - | - | - | - | - | - | - |
| Diospyros virginiana (persimmon) | 1.2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Fagus grandifolia (beech) | 12.2 | 1.5 | 29.1 | 6.0 | 7.1 | 6.6 | 29.5 | 11.1 | 2.5 | 0.8 | 18.0 | 2.1 | 3.4 | - | 26.2 | 8.6 | 2.6 | 1.5 |
| Fraxinus spp. (see text) (ash) | 7.3 | 7.5 | 9.1 | 7.4 | 12.2 | 9.0 | 8.2 | 3.2 | 12.5 | 13.1 | 4.0 | 4.3 | 10.3 | 16.7 | 5.4 | 3.7 | 14.9 | 21.8 |
| Gleditsia triacanthos (honey locust) | 1.2 | 5.6 | 0.9 | 0.6 | 1.1 | 1.8 | - | 3.2 | 2.5 | 4.9 | - | - | - | - | - | - | - | - |
| Gymnocladus dioica (coffee tree) | - | 4.5 | - | - | 0.3 | 0.7 | - | - | - | 0.8 | - | - | 1.7 | 6.0 | - | - | - | - |
| Hamamelis virginiana (witch hazel) | - | - | - | - | + | + | - | - | - | - | - | - | - | - | - | - | - | - |
| Juglans nigra/cinerea (walnut) | 6.1 | 9.1 | 4.3 | 3.7 | 3.6 | 4.3 | 7.1 | 9.5 | 16.3 | 13.9 | 16.0 | 8.5 | 13.8 | 4.8 | 1.2 | 2.4 | 12.9 | 29.8 |

Table 1 (continued).

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Juniperus virginiana (cedar) | 1.2 | 0.8 | - | - | 0.3 | + | - | - | - | - | - | 4.3 | - | - | - | + | 0.9 | 0.2 |
| Liriodendron tulipifera (poplar) | 7.3 | 2.6 | 2.1 | 2.5 | 0.5 | 1.3 | 12.9 | 6.3 | 5.0 | 2.5 | 18.0 | 2.1 | 8.6 | 1.2 | 2.1 | 1.5 | 0.1 | 0.1 |
| Liquidambar styraciflua (sweetgum) | 1.2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Magnolia acuminata? (cucumber tree) | - | 0.8 | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| Malus coronaria (crab apple) | 1.2 | 0.8 | - | - | - | 0.1 | - | - | - | - | - | - | - | - | - | - | - | - |
| Morus rubra (mulberry) | - | 4.1 | 0.4 | 1.0 | 1.2 | 1.2 | - | - | 2.5 | 3.3 | - | 2.1 | 5.2 | 4.8 | - | - | - | - |
| Nyssa sylvatica (gum, blackgum) | 2.4 | - | 0.6 | 1.9 | 0.2 | 0.4 | 1.1 | 1.6 | - | - | 2.0 | - | - | - | - | 1.3 | 0.3 | 0.2 |
| Ostrya virginiana (ironwood) | - | 0.8 | 1.3 | 1.4 | 1.3 | 0.6 | - | - | 1.3 | - | - | 2.1 | - | - | - | - | - | - |
| Quercus Lepidobalanus (white oak spp.) | 13.4 | 4.1 | 7.3 | 21.4 | 9.1 | 10.4 | 11.8 | 22.2 | 3.8 | 8.2 | 14.0 | 27.7 | 15.5 | 15.7 | 18.2 | 31.1 | 25.1 | 12.2 |
| Quercus Erythrobalanus (red, black oak spp.) | 6.1 | - | 1.5 | 5.6 | 3.6 | 5.3 | 1.1 | 14.2 | 2.5 | 4.1 | 4.0 | 14.9 | 5.2 | 3.6 | 16.4 | 21.0 | 13.5 | 7.1 |
| Pinus virginiana/echin. (pine) | 1.2 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 1.0 | - | - |
| Platanus occidentalis (sycamore) | - | 1.5 | 1.7 | 1.8 | 0.4 | 0.6 | - | - | - | - | - | - | - | 1.2 | 3.9 | 1.6 | 2.0 | 1.7 |
| Populus deltoides (cottonwood) | - | - | + | 0.1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Prunus serotina (cherry) | - | 6.4 | 0.2 | 0.7 | 0.4 | 0.8 | 1.1 | - | 3.8 | 5.7 | - | - | 5.2 | 13.3 | - | - | - | - |
| Prunus spp. (plum) | - | 1.9 | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Robinia pseudoacacia (locust, black locust) | 3.7 | 5.3 | 0.4 | 0.3 | 0.8 | 1.0 | 2.2 | - | 2.5 | 6.6 | 2.0 | - | - | 1.2 | - | 1.5 | 0.7 | - |
| Sassafras albidum (sassafras) | 3.7 | - | 0.3 | 0.3 | - | 0.1 | - | - | 1.3 | - | 2.0 | 2.1 | - | - | - | - | - | - |
| Tilia americana/hetero. (lynn, basswood) | 1.2 | 0.8 | 1.7 | 0.5 | 1.9 | 1.0 | - | - | - | - | 4.0 | - | 3.4 | 2.4 | 0.2 | 0.8 | 0.4 | 0.2 |
| Ulmus rubra/americana (elm) | 1.2 | 4.9 | 4.8 | 4.8 | 5.7 | 6.7 | 1.1 | - | 1.3 | 3.3 | - | 2.1 | 3.4 | 2.4 | 2.3 | 1.7 | 1.5 | 1.3 |
| Viburnum prunif./rufid. (blackhaw) | - | 1.1 | - | 0.4 | - | - | - | - | - | - | - | 2.1 | - | - | - | - | - | - |
| Other | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 3.4 | 3.3 | 5.6 | 2.7 |
| Total tree records | 82 | 266 | (>100 per county) | | | | 91 | 63 | 77 | 122 | 50 | 47 | 58 | 83 | (board-feet basis) | | | |

*Table 1 (explanation).

ACCOUNTS OF 1750-1850. These include a few peripheral areas in S Ohio and the Knobs Region.
A. Areas on poorer soil dominated by beech, oaks or poplar (Anon. 1791, Imlay 1792, Parry 1794, Barrow 1795, Smith 1797, Bartlett 1805, F. Michaux 1805, Melish 1807, David 1816, Short 1828, Lyell 1842, Collins 1847).
B. Areas on richer soil dominated by walnut, sugar maple, ash, honey locust, cherry, buckeye, etc. (Gist 1751, Hanson 1774, Fleming 1780, Filson 1784, Morse 1789, Imlay 1792, A. Michaux 1793, Parry 1794, Barrow 1795, Smith 1795, Harris 1797, Ellicott 1803, F. Michaux 1805 and 1819, Melish 1807, Marshall 1812, Flint 1822, Short 1828, Flint 1832, Drake 1840s, Clinkenbeard 1840s, Matthew 1840s, Collins 1847, Finley 1853, Chenault 1880s).

DEED SURVEYS OF 1780-1840 (and Robertson Co. in 1866). See figure 3 for geographic details.
C. Counties with beech as the most frequent tree.
D. Counties with the white oak group as the most frequent trees.
E. Counties with sugar maple or buckeye as the most frequent trees.
F. Counties with hickories most frequent.

GEOLOGICAL SURVEY OF OWEN (1857).
G. Areas dominated by beech or poplar.
H. Areas dominated by white oak.
I. Areas dominated by sugar maple, mixed with walnut and ash.
J. Areas dominated by black walnut, bur oak or blue ash.

GEOLOGICAL SURVEY OF LINNEY (1882-87).
K. Areas dominated by beech or poplar.
L. Areas dominated by white oak.
M. Areas dominated by sugar maple, mixed with walnut and ash.
N. Areas dominated by blue ash, mixed with oaks and hickories.

FOREST REPORT OF BARTON (1919).
See Figure 4 for geographic details.
O. Counties with beech or beech and maple as the most abundant trees.
P. Counties with oaks and hickories as the most abundant trees.
Q. Counties with oaks and ashes or oaks and walnut as the most abundant trees.
R. Counties with walnut as the most abundant tree.

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The trees most frequently listed in early deed surveys were sugar maple, beech, white oaks (as a group) and hickories (table 1). Sugar maple was the most frequent tree in central, southern and eastern sections, while beech was most frequent in western and northern sections (fig. 2). The oaks were most frequent in a few northeastern and southwestern counties, while the hickories were most frequent in a few south-eastern counties. In addition, buckeye and ashes were locally abundant in some areas, but less often to the west and north. Outside the Bluegrass Region, in the Knobs Region and on the adjacent Mississipian Plateau and Appalachian Plateaus, white oaks or black oaks were generally the most frequent trees in these surveys.

In general, the tree composition indicated by these deed surveys is similar to that indicated by the early landscape descriptions. However, there are considerable differences in the frequencies of some trees, especially on more fertile soils (table 1, comparing columns C-F with A-B). Species that are generally at least 25% more frequent (as a proportion of the total) in deed surveys are sugar maple, boxelder, buckeye, hornbeam, hickory, dogwood, beech, ash, oaks, basswood and elm; those that are at least 25% less frequent are pawpaw, redbud, hawthorn, honey locust, coffee tree, walnut, yellow poplar, mulberry, sycamore, cherry and black locust. The latter species are generally more early successional (Campbell 1980). Early successional species may have been listed less often at boundaries because disturbed areas were concentrated on broad ridges or bottoms with relatively deep soils, where pioneers would have centered settlements. Also, some of these species may have been avoided for marking boundaries due to their shorter lifespans. In contrast, people who attempted to describe the landscape may have given early successional trees a positive bias, because they were seen more frequently along trails and at the centers of settlements.

## EARLY GEOLOGICAL AND FOREST SURVEYS

### Owen (1857)

David Dale Owen (1857) included many notes on forest composition in his geological surveys of individual counties. Wherever possible, he referred to areas of "primitive", "virgin" or "original" growth. His notes were fairly systematic, with a few typical sites described in each county. He referred to soil analyses by Robert Peter (1857-61), which indicate the forest types that were associated with high or low fertility. In order to summarize these data, his various sites were grouped into forest types, based on dominant species and characteristic associates. The percentage composition of each forest type was estimated from the number of times that tree taxa were listed at individual sites (table 1). Into this synthesis are also incorporated a few additional notes made by N.S. Shaler and other workers in the Geological Survey during a slightly later period (Peter 1876-1884).

The generalized forest types can be described as follows (see also table 1, which combines d-f).
(a) Beech-dominated forest (26 sites), with occasional dominance of poplar, also including sugar maple, oaks (mostly "white"), hickories

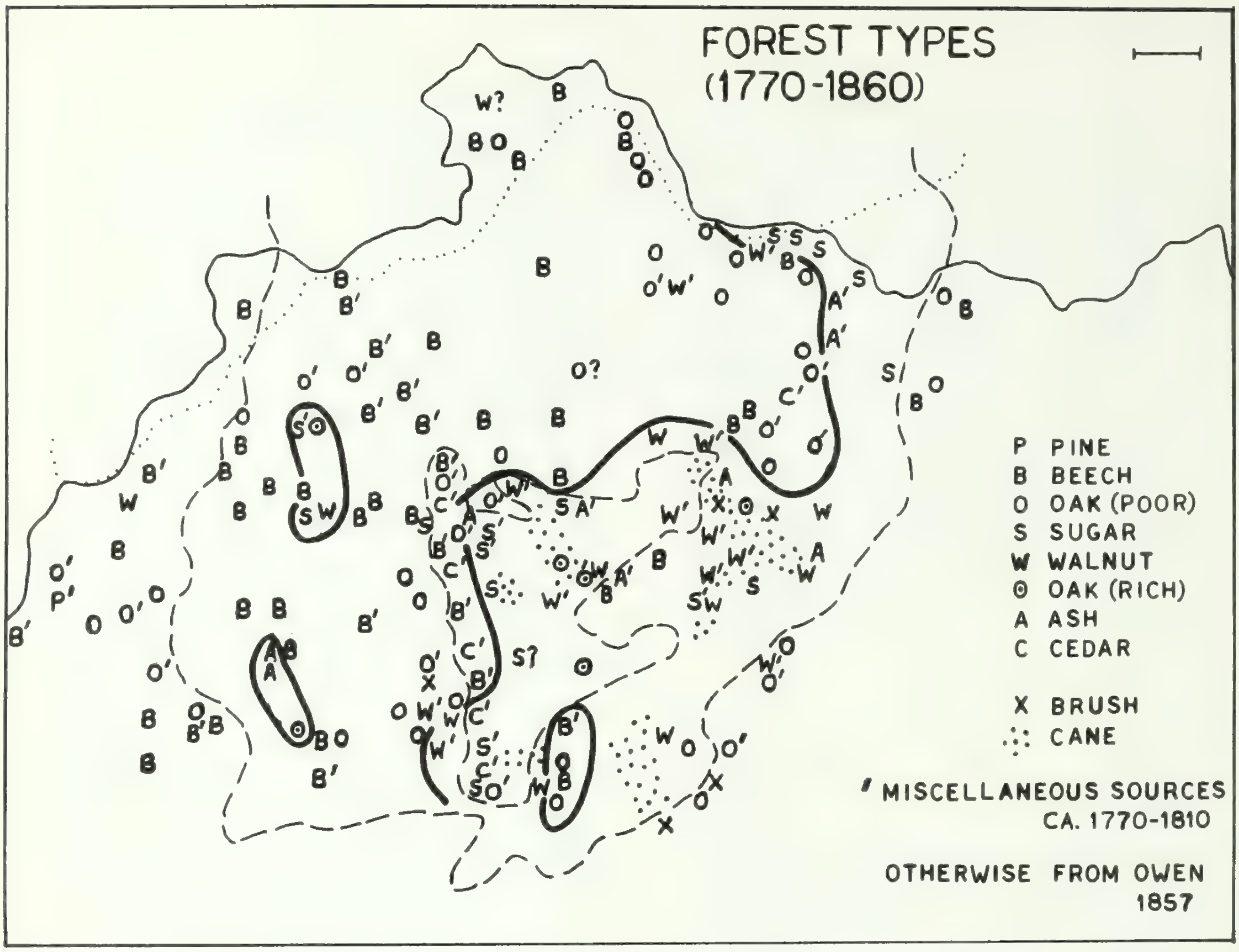


Figure 2.-- Indications of forest type distributions, derived from early (ca. 1770-1810) accounts (shown with ') and Owen (1857). Dashed lines are boundaries of the Bluegrass and Inner Bluegrass Regions (see Figure 1). Symbols indicate the commonest woody species noted by an observer at that location. Some less abundant trees have been combined with their associated dominants: locust and buckeye with walnut; elm with ash; yellow poplar with beech. "Poor" oak refers to white oak and associates on less fertile soil; "rich" oak refers to bur oak, yellow oak and associates on more fertile soil. Solid lines show the separation between trees typical of more or less fertile soils (see text).

(mostly "shellbark"), walnuts, ashes and other minor species.
(b) Oak-dominated forest (mostly "white" with some "red"; 23 sites), including hickories, beech, sugar maple and other minor species.
(c) Sugar maple forest (with no pronounced dominance; 15 sites), including black walnut, ashes (mostly "black"), oaks, buckeye and other minor species.
(d) Black walnut forest (with no pronounced dominance; 13 sites), including sugar maple, ashes (mostly "blue"), oaks, locusts (mostly unspecified), cherry and other minor species.
(e) Bur oak forest (with no pronounced dominance; 4 sites), including ashes, hickories, honey locust, buckeye, sugar maple and other minor species.
(f) Blue ash forest (with other ashes; 6 sites), including sugar maple, walnut (unspecified), hackberry, oaks and other minor species.

Most of these types occurred on the most fertile soils in the Inner and Outer Bluegrass, except for the beech and white oak types, which were mostly on less fertile soils in the Eden Shale or Outer Bluegrass. Shaler (1880s) wrote that blue ash, black walnut, black locust and coffee tree indicated the "best" soils, while beech, white oak, red oak, black oak and blackjack oak indicated progressively "worse" soils (see also R. Peter in Perrin 1882, p. 11, 20).

On the adjacent Silurian dolomitic rocks, Owen indicated that beech and poplar were the most frequent dominants, and that white oak, hickories, sugar maple, black walnut and ashes were also widespread. However, the "Beargrass Lands" of Jefferson County, near the old buffalo route between Louisville and Frankfort, were quite distinct. This area was dominated by black walnut, together with others typical of the more

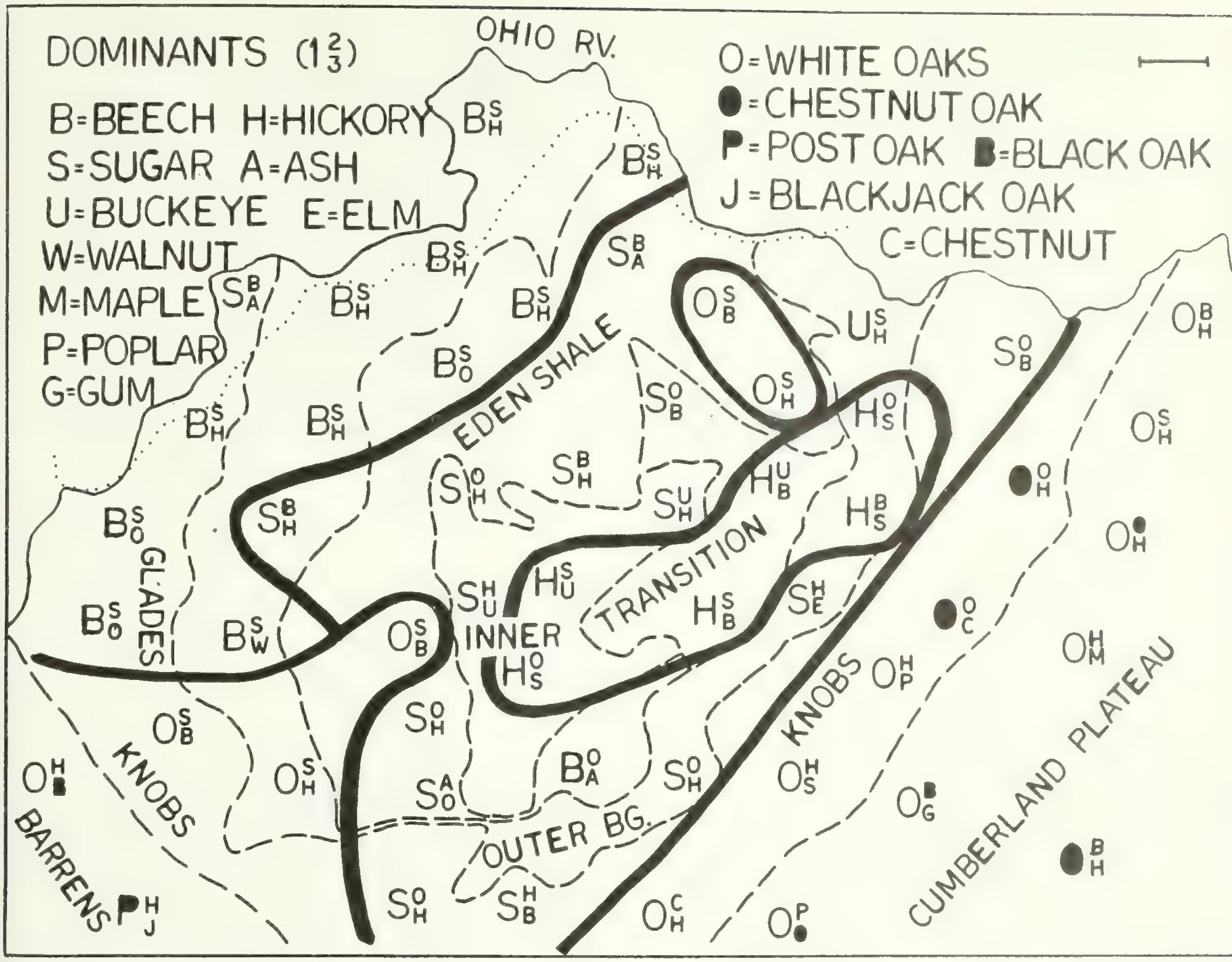


Figure 3.-- Dominant trees in each county (see fig. 1) based on samples from early deed surveys (mostly 1780-1840). Types of tree are indicated by single letter symbols. The second and third most frequent trees in each county are shown by the smaller symbols to the right of the most frequent tree symbol.

fertile Bluegrass soils: black locust, cherry, elm, ash, hackberry, boxelder, buckeye, hickories ("pignut and shellbark"), coffee, oaks ("red" and "overcup"), sugar maple and beech.

The geographic aspects of Owen's (1857) data, together with the various notes of earlier observers (from the previous section), are summarized here in the form of a preliminary natural vegetation map of the Bluegrass Region (fig. 2). This map shows that trees typical of more fertile soils were concentrated in central and southeastern sections. There were also small concentrations of these trees in the western Outer Bluegrass. Beech was predominant in the west and oaks (mostly white oak) in the north.

## Linney (1882-87)

William Linney (1882-1887) also made notes on forests during some geological surveys, allowing percentage compositions to be estimated in the same way. He made more precise species identifications and geological correlations. However, his work covered only some western, southern and eastern sections of the Bluegrass Region, excluding most of the Inner Bluegrass. He had difficulty finding undisturbed forests representative of each county, and he often deplored the wasteful deforestation that had occurred.

His notes largely confirm the patterns shown by Owen. The following forest types can be described from his data (tables 1 and 2).

(a) Beech forest. This was largely restricted to Upper Ordovician Garrard Siltstone ("Middle Hudson siliceous mudstone"). Poplar again was a locally dominant associate; other species included sugar maple, walnuts and white oak.

(b) White oak forest. This was concentrated on shaley soil on lower and upper strata of the Upper Ordovician, i.e., the Clays Ferry ("Lower Hudson") and the Drakes Formation, etc. ("Upper Hudson"). Associates on the lower strata

Table 2.--Common trees noted by Linney (1882-87) on different geological strata in several counties*.

| Geological Strata | Western Counties | | | | Southern Counties | | | | | Eastern Counties | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Old | She | Spe | Nel | Was | Mar | Gar | Lin | Mad | Cla | Mon | Bat | Fle | Mas |
| Silurian Strata | B<br>g | | | P<br>o<br>c | G<br>o<br>c | G<br>W<br>o<br>c | G<br>o<br>c | G<br>o<br>c | G<br>o<br>c | | | W | B<br>g<br>p<br>o | |
| Outer Bluegrass Limestones ("Upper Hudson") | B<br>W<br>S<br>a | B<br>s<br>a | B<br>W(u)<br>s<br>a(1) | a(1) | W<br>A | W<br>s<br>a(1) | W<br>a(1) | W<br>a(1) | W<br>a(1) | | b<br>w<br>A | W(u)<br>a(1) | W(u)<br>a(1) | W(u)<br>a |
| Garrard Siltstone ("Middle Hudson") | | | B | B | B | B<br>w<br>s | B<br>w<br>s | B<br>w<br>s | B<br>w<br>s | W<br>S | a<br>S | b<br>s | b<br>w<br>s | B<br>o<br>s |
| Clay's Ferry Shale ("Lower Hudson") | | | W | | W<br>s | W | W | W | W | W | | | W | |
| Inner Bluegrass Limestones ("Trenton") | | | | | c(u)<br>A<br>w(1)<br>b(1) | c(u)<br>A<br>w(1)<br>b(1) | c(u)<br>A<br>w(1)<br>b(1) | c(u)<br>A<br>w(1)<br>b(1) | c(u)<br>A<br>w(1)<br>b(1) | A<br>y | | | | |
| High Bridge Strata | | | | | c | c | c | c | c | | | | | |

* Symbols for different trees are:
a = ash (mostly blue); b = beech; c = cedar;
g = sweetgum; o = post oak; p = yellow poplar;
w = white oak; y = yellow (chinquapin) oak.

Upper case symbols indicate the most widespread dominant species. In parentheses, symbols show restriction to upper (u) or lower (1) strata. See fig. 1b for full county names and locations.

included sugar maple, red oak and hickories, with some groves of post oak and "laurel" (shingle) oak. Associates on the upper strata included black oak, hickories, post oak, sugar maple and walnuts.

(c) Mixed forest with sugar maple or walnuts (mostly black) most abundant. This was typical of some soils on Garrard Siltstone and on the overlying Ashlock or Calloway Limestones. Associates included yellow (chinquapin) oak, blue ash, white oak, poplar, red oak, hickories, cherry and mulberry.

(d) Mixed forest dominated by blue ash or yellow oak. This was typical of the Ashlock and Calloway Limestones in the Outer Bluegrass, and the Lexington ("Trenton") Limestone in the Inner Bluegrass. Cherry and hackberry were consistent associates. Less frequent species included shellbark hickory, coffee tree, sugar maple and mulberry.

Linney noted that there was an east-west shift on the Garrard Siltstone, and he added some detail to the geographic pattern in earlier data (Table 2). In the west, beech alone was the typical dominant. In the east, sugar maple was a local dominant as well as, or instead of, beech and white oak.

On the narrow zone of Silurian dolomite and shale surrounding the Bluegrass, Linney reported some distinct types indicative of poorer soils, though intermixed with species of more fertile soil. The forest on less fertile soil included "Spanish oak" (specified as Quercus falcata) and sweetgum, which are virtually absent from past or present records of the Bluegrass Region.

## Barton (1919)

One final source that provides some insight to natural forest composition is the 1919 report of J.E. Barton, Commissioner of Geology and Forestry in the State Government. This was the first estimate of timber volumes throughout the state, giving details of composition by county. However, no information on survey methods was given. Barton simply stated: "The only figures available date back some years and a large share of the removal of the timber in Kentucky, due to large operations, has taken place within a recent period... the figures here given were compiled under conditions which do not permit an extremely close and careful estimate... experience heretofore has shown that estimates of standing timber usually fall considerably below the actual cut." The forest cover estimated for the

Bluegrass Region in this report was only 5-6%, but much of this was probably old growth. Currently, "commercial forest land" is estimated to cover about 20% of the region (Kingsley & Powell 1978), much of which is on farmland abandoned since 1900.

There is some consistency between Barton's (1919) data and notes in contemporary county histories. In Franklin County, Johnson (1912) listed 12 major tree genera, as did Barton, and 10 were shared. Johnson listed walnut, ash, beech and oak as the major timber sources; these were all among the five most abundant trees in Barton's data (adding hickory). In Fayette County, Perrin (1882) listed seven major tree genera in common with Barton, out of 10-11 in each source. Those noted at least twice in Perrin's account were mostly (except honey locust and buckeye) the five most abundant trees in Barton's data: walnut, ash, oak, hickory and maple.

Barton's (1919) report listed seven Bluegrass counties that had forests dominated by beech, or by beech codominant with maple (table 1, fig. 4) or with oaks (all species combined). These counties were mostly in the western section. Another 14 counties, mostly to the north and east, were dominated by "white oaks", with almost equal amounts of "red oaks" and lesser amounts of hickories, beech, maple, etc. Eight counties were transitional from this oak dominance to ash and walnut, mostly in central and southeastern sections. Only the two most central Inner Bluegrass counties (Woodford and Fayette) were dominated by walnut, with ashes almost as abundant, followed by oaks, hickories, maple and other minor trees. Unlike earlier data, the peak abundance of walnut and ash was only in the central Bluegrass, without much extension towards the southeast. Most minor trees showed little geographic pattern, except for hackberry, which was only listed in the Inner Bluegrass and the transitional counties.

When other regions of the state are compared, these data clearly show the distinctiveness of the Bluegrass Region (fig. 5). The only Kentucky counties reportedly dominated by trees typical of the most fertile soils (oak-ash and walnut-maple) occurred in this region. Among major successional trees on moist sites, walnut exceeded yellow poplar in 23 of the 33 Bluegrass counties, but in no other Kentucky counties. Among major mesic climax trees, maple (mostly sugar maple in the Bluegrass) exceeded beech in 21 of the 33 Bluegrass counties, compared to 20 of the other 87 (including 12 in the western bottomlands probably referring to red maple). However, beech was still dominant in seven Bluegrass counties, in contrast to only four elsewhere in the state. Moreover, sugar maple was nowhere the county dominant, being replaced on the more fertile soils by more early successional trees like walnut.

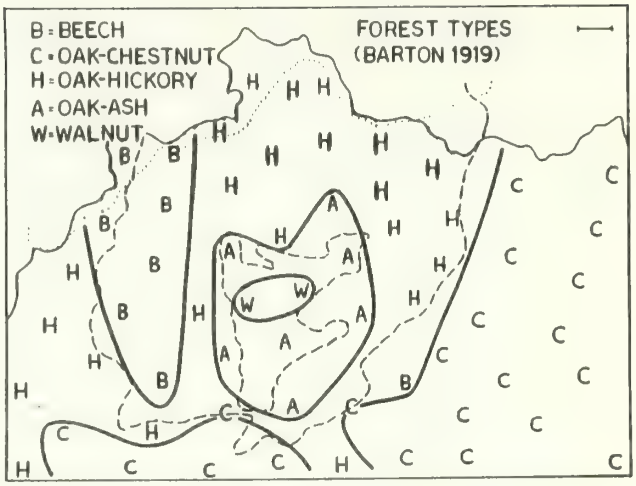


Figure 4.--Dominant trees in each county (see fig. 1) according to Barton (1919). Congeners are combined. One "B" has maple slightly more abundant than beech; one "A" has walnut slightly more abundant than ash.

Among trees generally typical of somewhat drier sites (subxeric), ash exceeded hickory in 11 Bluegrass counties, but in only two marginal counties elsewhere in the state. Also, the white oak group was more abundant than the black (or red) oak group in contrast to most other regions of the state. In the whole state, beech and walnut were the only county dominants that are truly mesic trees; both were concentrated in the Bluegrass Region. Elsewhere in Kentucky, subxeric trees were dominant in almost all 87 counties: oak-chestnut mostly in the east, and oak-hickory mostly in the west. The only exceptions were four scattered counties with beech, and four western bottomland counties with gum (Nyssa or Liquidambar).

## DISCUSSION

### Interpretation of presettlement composition

The major patterns of presettlement species composition suggested by these data can be interpreted with the aid of a general scheme of compositional gradients generated from modern data in the Central Hardwood Region (Campbell 1987). Much of the special character of Inner Bluegrass forest composition can be attributed to the moist, fertile soils that predominate here, favoring sugar maple, black walnut, ashes and other species that are generally concentrated on such soils in eastern North America. Also, the presettlement importance of early successional species like black walnut may be attributed to prior disturbance by Indians and large native herbivores (see Introduction).

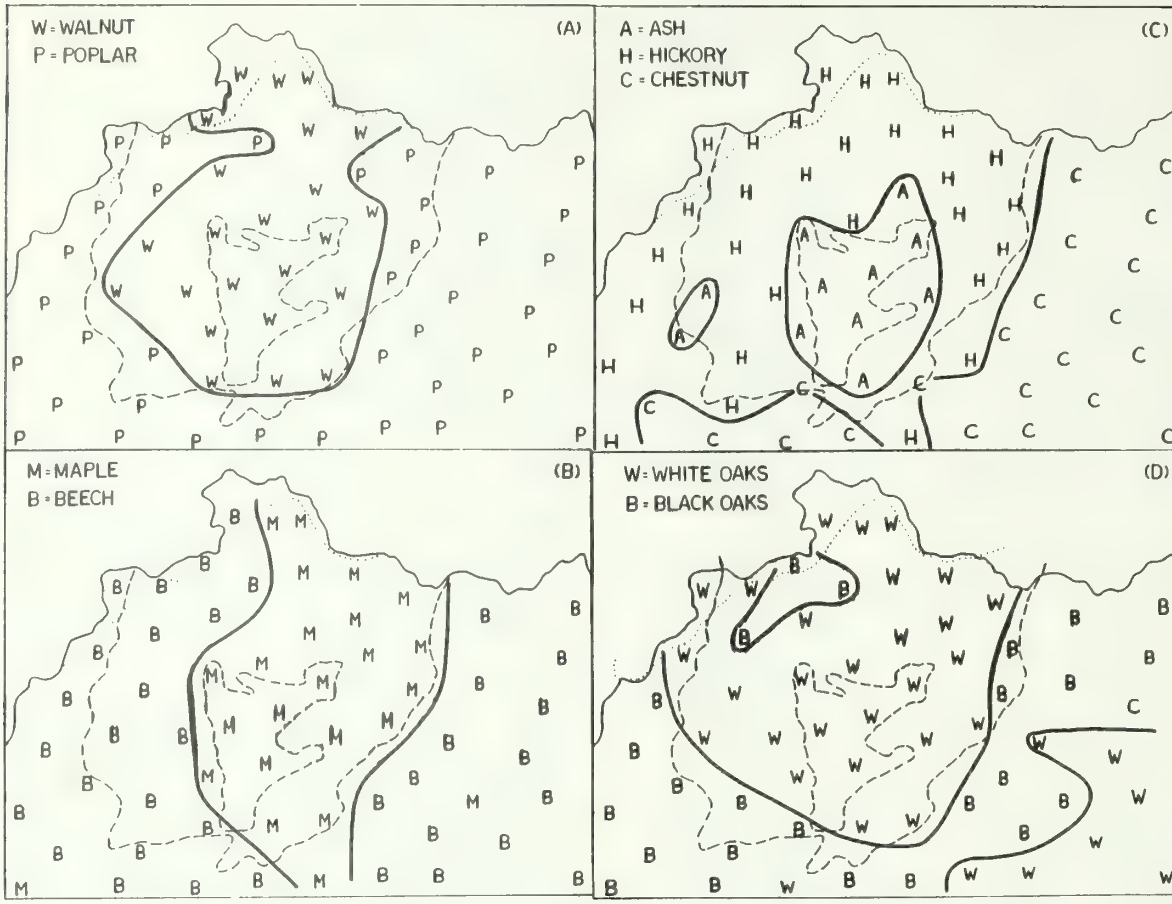


Figure 5.-- Contrasts in some tree distributions, from data in Barton (1919). In each county (see fig. 1), symbols show the most abundant tree within small ecological groups of taxa selected to show geological relationships.
(a) Walnut versus yellow poplar (successional dominants on moist sites).
(b) Maple (mostly sugar) versus beech (climax dominants on moist sites).
(c) Ash, hickory and chestnut (codominants with oaks on drier sites).
(d) White oak group versus black (or red) oak group (drier site dominants).

However, there was also a group of species in the presettlement forests on more fertile soils whose frequency gave this region some further unusual character that is not easily interpreted in terms of major regional compositional gradients. These species are Ohio buckeye, honey locust, coffee tree, pawpaw and, in the shrub layer, cane (Arundinaria gigantea). They appear to have been loosely associated with each other (Campbell 1980, and unpublished). It has been hypothesized that these species were formerly concentrated in ecotonal areas between the most frequently disturbed areas and the less disturbed forests of sugar maples, hickories, ashes and oaks (Campbell 1980). Such ecotonal vegetation may have been relatively stable, being maintained by small-scale oscillation of forest boundaries rather than long-term directional succession. These species have defenses (toxins, thorns) or reproductive characteristics (strong vegetative regeneration, poor seed dispersal) which may suit them to stable regimes of moderate disturbance. The extremes of clearance or abandonment that prevail over the landscape today do not appear optimal for them. In general, these species remain vigorous competitors in areas where they have not been cleared out, but they do not spread rapidly into either early or late successional forest types.

The geographic separation between trees typical of more fertile and less fertile soils approximately matches the soil differences mapped by U.S.D.A. (1974), but an unexpected trend shown above is the predominance of beech in the western and northern Bluegrass. In the highly disturbed modern landscape, beech is uncommon even within less disturbed forest remnants. However, if the general concentration of beech on soils of moderate pH and fertility is considered (see also Campbell 1987), this particular geographic pattern may be attributed to two general edaphic factors: (a) in the west and north, there is more land within the Eden Shale Belt, including the

Garrard Siltstone where beech was concentrated; and (b) there are also increases in loess content towards the west (deposited during glacial eras), and in pre-Wisconsin glacial material towards the north, both of which may reduce the pure limestone influence on flatter Outer Bluegrass soils.

## Changes since settlement

In the modern landscape, typical early successional species have generally increased due to human disturbance (Campbell 1980). However, there appear to be some further changes in composition that are not simply attributable to the younger stand ages today. The possible importance of special ecotonal conditions for maintaining certain species before settlement has already been mentioned. The apparent decline of beech in the northwest has also been noted. It is conceivable that erosion of more acid upper soil horizons, along with forest clearance, has made the area less suitable for beech growth, but much more ecological work is needed to test this and other hypotheses.

Other important shifts appear to have occurred among the dominant species on more fertile soils, based on the data presented above (fig. 6). These shifts cannot be taken as conclusive results, since the various sources may have important differences in sampling biases, but they do suggest hypotheses for further research. Even in Owen's (1857) survey, some early shifts are indicated, though sugar maple and walnut remained about equally dominant in his data. In the later data of Linney (1882-87) and Barton (1919), there was a large shift to dominance by oaks and ashes. Then, in modern forests of the Inner Bluegrass, which are largely early successional, there has been some return to walnut, but with much more hackberry and other species instead of sugar maple.

The apparent increase in importance of the oak-ash component during the previous century may be explained by two general hypotheses.

(1) There may have been selective clearance of the maple-walnut component. This component is typical of soils with lower moisture stress that are most suitable for intensive agriculture. Much of the somewhat drier land dominated by oaks and ashes, especially blue ash, may have been set aside for less intensive use as "woodland pasture". Possibly there was also a higher demand for sugar maple and black walnut timber. The selective effects of livestock should also be considered. Sugar maple, in particular, is highly palatable to large herbivores (unpublished data) and may have been prevented from regenerating in many areas.

(2) There may have been ecological changes within the forests, due to natural factors (including climatic fluctuations) or human factors (deforestation and drainage). Drier conditions would have have reduced growth and survival of the maple-walnut component relative to the oak-ash component. Possibly pests and pathogens also played a role. Barrow (1795) noted that the region had been "much afflicted with caterpillars for seven or eight years past. They have done much damage in the woodlands especially among the sugar trees. By leaving them bare so many years an abundance of that valuable growth is dead." The disease of white walnut (_J. cinerea_) may also be involved (see Notes on Common Names).

Today, older trees on the more fertile soils are typically scattered in pastures. Blue ash is most common, with yellow (chinquapin) oak, bur oak, shumard oak (_Quercus shumardii_) and shellbark hickory (_Carya laciniosa_) also frequent. The size-class distributions of trees in the best preserved woodland-pastures or "savanna-woodlands" suggest that most of the trees originated during the 19th century, though the oldest are up to 450 years old (Bryant et al. 1979, Bryant 1983). If there really was some resurgence of more drought-tolerant species (oaks, ashes and hickories) within forest remnants during this period, actual change in moisture levels might be suspected. Some subsequent reversal might be suggested by the current failure of blue ash and yellow oak to regenerate in either ungrazed or grazed woodland-pasture remnants, which instead are often invaded by hackberry, black walnut and other mesic successional species. This hypothesis could be examined by looking for relationships between tree growth and land-use history or climatic factors. There is much potential for studies of tree rings in this context.

In conclusion, there is much to be learnt from historical data on forests in the Bluegrass Region, where so much of the modern landscape is agricultural. This initial study has shown that natural forest composition, and its variation over the landscape, can be estimated from such data. Some results are unexpected or difficult to interpret, but several hypothesis concerning ecological factors can be put forward to explain them. To test these hypotheses will require more analysis of spatial patterns in historical data, together with more intensive studies of modern forest ecology, including some population dynamics and physiology.

## ACKNOWLEDGEMENTS

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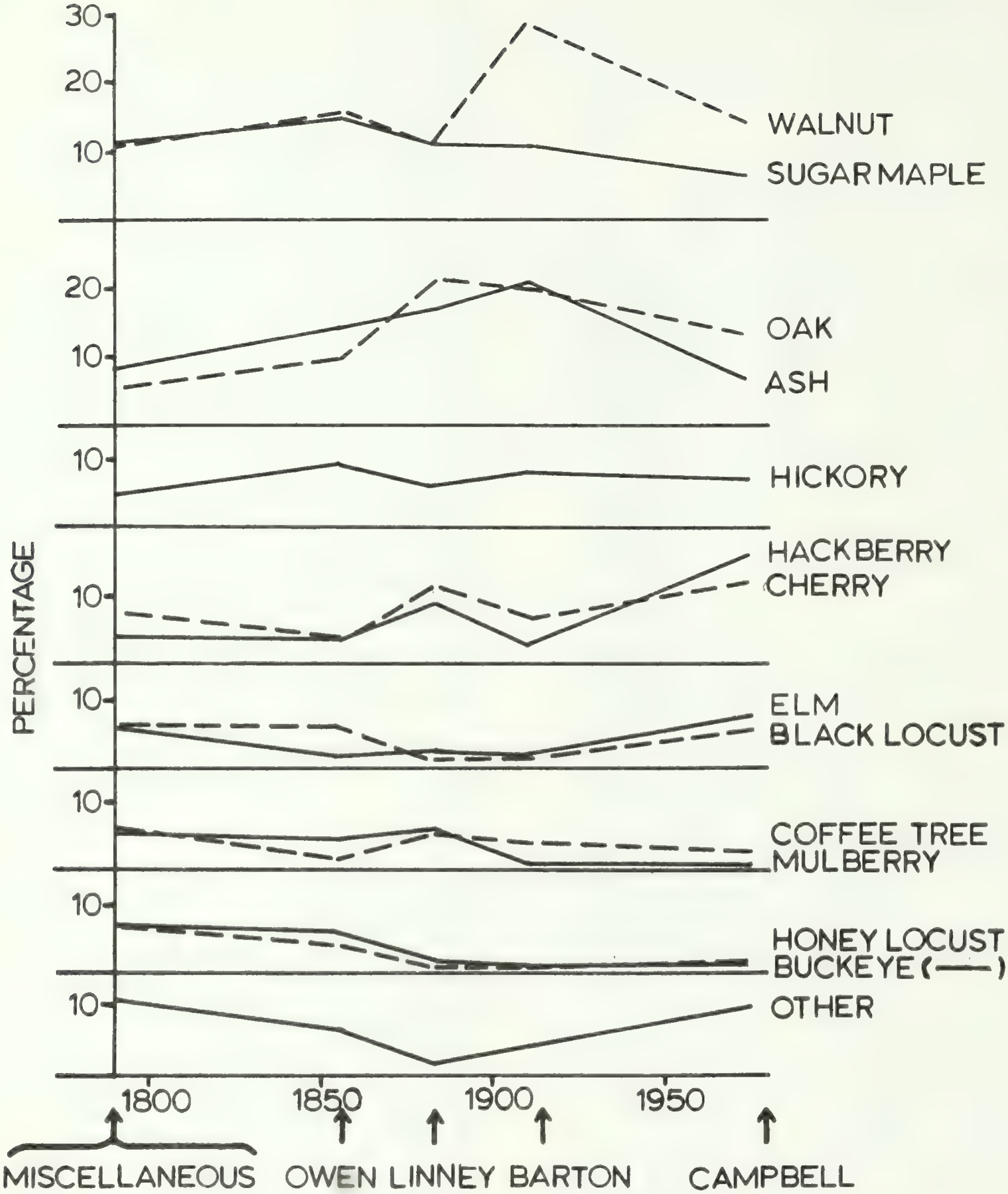


Figure 6.--Temporal shifts in forest composition on more fertile soils (mostly in the Inner Bluegrasss), as suggested by miscellaneous early landscape descriptions (Table 1:B), Owen (Table 1:J), Linney (Table 1:N), Barton (Table 1:R) and Campbell (1980, p. 63; mean basal area of successional phases D-G). Small trees like pawpaw, dogwood, redbud, hawthorn, hornbeam and ironwood are excluded from these percentages.

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COMPOSITION AND STRUCTURE OF AN OLD-GROWTH

OAK-HICKORY FOREST IN SOUTHERN MICHIGAN OVER 20 YEARS[1]

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Abstract.--A 150-year-old oak hickory forest in southern Michigan was surveyed vegetatively in 1968 and again in 1988. Composition, density, and stand structure were determined for all tree species above 1-in dbh. Woody stems less than 1 in dbh were identified and abundance was determined. In 1968, 85% of the canopy species consisted of Quercus rubra, Q. alba, and Q. velutina, with Q. alba comprising 44% of the oaks. Acer rubrum, Q. alba, Prunus serotina and Ulmus americana were most prominent in the subdominant canopy, and A. rubrum was most abundant in the understory. Acer saccharum was the most dominant ground cover species. Major changes after 20 years show less Q. velutina in the canopy, due to death and blow down, and less Sassafras albidum, Prunus serotina, and Q. alba in the intermediate canopy. Acer saccharum has been the most dynamic species in the understory during the period, and Fraxinus americana the most common ground cover species.

## INTRODUCTION

Oak-hickory forests extend northward into the southern third of lower Michigan as part of the "Prairie Peninsula" section of the Oak-Hickory Forest region (Braun 1950). These forests were intermixed with prairie communities. Küchler (1964) shows widespread areas of oak-hickory forest as the potential natural vegetation of Southeastern Michigan. In addition, beech-sugar maple forests occupied the mesic sites of glacial moraine with their relatively heavy-textured soils (Albert et al. 1986). Oak-hickory forests occupied the fire-prone, dry and dry-mesic sandy sites on level to gently rolling glacial outwash and hilly ice-contact terrain. Much of the former beech-sugar maple forest has been cleared for agriculture leaving scattered, cut-over tracts of oak-hickory forest. Radrick Forest is one such remnant stand.

Old-growth forests--their composition, structure and management--are of increasing importance in forest management today (Crow 1988; McGee 1986; 1984; McCune and Cottam 1985; Romme and Martin 1982; Lorimer 1980). Although the literature on central hardwoods contains several detailed descriptions of forest stand composition and structure (Parker et al. 1985; Nigh et al. 1985; Della-Bianca 1983; Muller 1982), few studies are restricted to old-growth oak-hickory forests in Michigan.

The major purpose of this paper is to provide baseline information on the species composition and structure of a 150-year-old oak-hickory forest in southeastern Michigan, first sampled in 1968. The forest was re-surveyed in 1987-1988, using the permanent sample plots of 1968. Specific objectives of the paper are to: (1) describe the woody species composition, size classes, and forest types as they appeared in 1968 and (2) examine the major changes that have occurred in the forest over the last 20 years.

## STUDY AREA

The Radrick Forest is in Washtenaw County (Ann Arbor and Superior townships) in southeastern Michigan. The forest is part of the Matthaei Botanical Gardens of the University of Michigan, located 5 mi east-northeast of Ann Arbor. The 35-acre upland oak-hickory forest is mostly on glacial-outwash and ice contact sandy soils (Boyer and Fox series), but about 10 acres occupy till soils of the Miami series. Texture of the soils are primarily sandy loams and sandy clay loams (Hammitt 1969).

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The General Land Office Survey for Radrick Forest was conducted in 1819. The original survey notes for a section corner within the study area described the vegetation as "black oak, red oak, white oak, hickory, and black walnut--undergrowth of hazel and sassafras." The diameters of the witness trees were: black oak--20, 24, 36, 40 inches, 20-in lynn (basswood), and a 13-in white oak. The land was described as being a little hilly. Radrick Forest was similar in 1968, except for smaller diameter trees and the presence of a few black walnut (Juglans nigra L.).

History of the forest suggests that it was logged in the 1820s, as tree ring counts made of seven dead trees logged[1] in the 1960s ranged from 129 to 140 years. An 1827-1829 map of the area also shows a road passing through the middle of the forest, and a sawmill on a stream within 1/2 mile of the study area. After the presumed initial logging of the forest, the area was owned by two families for over 100 years, with only a few selected trees being removed. Since 1939, the forest has been managed as a preserve.

## METHODS

### Field Measurements

The forest was type-mapped in 1968, based on a 20% strip cruise of dominant tree species. In addition, woody species were surveyed in 25-stratified randomly located plots, 10 by 20 meters (1/20 acre) . All tree species above 1 in dbh (diameter at breast height, 4.5 ft) were identified, measured, and recorded by 1 in diameter classes.

Nested quadrats of 0.5 by 8 meters (milacre) were located in each corner of the 25 plots for the purpose of sampling small woody plant saplings and reproduction under 1 in dbh. The amount of tree reproduction in two classes of woody ground cover was determined: (1) tall ground cover-plants under 1 in dbh but over 1 ft tall, and (2) short ground cover-plants under 1 ft in height.

In 1987-1988, the 25-permanent plots and nested quadrats were re-surveyed, using the same procedures and methods as in 1968. However, the 20% strip cruise could not be replicated, as the exact location of the strip cruise was not documented in 1968.

### Data Analysis

Forest types were analyzed at two levels, overstory and understory. Dominant canopy and understory tree species were used to map the boundaries of the major forest types. Relative density and board foot volume (Scribner rule) were calculated to help define the forest types.

Frequency and density of tree species were analyzed by forest type and by five size classes: (1) trees $\geq$ 12 inches dbh (dominant canopy), (2) trees 4 inches to 11.9 inches dbh (subdominant canopy), (3) saplings 1 to 3.9 inches dbh (understory), and (4) woody plants less than 1 in dbh but over 1 ft tall (tall ground cover), and (5) woody plants under 1 ft in height (short ground cover).

Relative densities and frequencies of species were calculated using methods of Curtis (1959) and Curtis and McIntosh (1951). Relative density was computed as the number of trees of any species relative to the total number of trees in any sample. Relative frequency was equal to the number of plots a species occupied relative to the total number of plots it could have occupied.

[1] Seven trees were cut because they were dead and near roadways. They were primarily black oak (Quercus velutina Lam.).

## RESULTS

### Canopy Composition and Forest Types

Radrick Forest is dominated by three species of oak: white (Quercus alba L.), black (Q. velutina Lam.), and red (Q. rubra L.). Of trees 10 in and greater dbh in 1968, 85.8% consisted of white, black, and red oak (Table 1). These same three species made up 91.8% of the board foot volume. White oak was the most common canopy species (density), whereas black oak was the most dominant in terms of volume. Pignut hickory (Carya glabra Mill.) is the only other species of much occurrence in the canopy.

Three forest types, White Oak/Mixed Hardwoods, Black Oak/Mixed Hardwoods, and Red-Black Oak/Red Maple were distinguished (Table 2). The White Oak/Mixed Hardwoods type consisted of mostly white oak in the 12- to 18- in size class and a few pignut hickory (Carya glabra Mill.), black cherry (Prunus serotina Ehrh.), American elm (Ulmus americana L.), and sugar maple (Acer saccharum Marsh.).[1] The Black Oak/Mixed Hardwoods type contained about an equal number of white and black oak, but the black oak was much larger (dbh) and dominant (note board foot volume). Pignut hickory and black cherry were the most prominent other species. The Red-Black Oak/Red Maple type was characterized by a canopy of red and black oak and an intermediate canopy of red maple (Acer rubrum L.). The greater proportion of red oak present in the canopy and red maple in the subdominant canopy distinguishes this type from the other two. The Red-Black

[1] Black maple (Acer nigrum Michx. f.) was included with sugar maple.

Table 1.--Proportion of oak composition in Radrick Forest, based on trees 10 inches and greater in diameter at breast height, 1968.[1]

| Species | Number of trees | Relative density (%) | Total relative density (%) of oak | Board foot volume[2] | Relative volume (%) | Total relative volume (%) of oak |
|---|---|---|---|---|---|---|
| Quercus rubra | 65 | 14.7 | | 17,471 | 23.4 | |
| Quercus alba | 195 | 44.0 | 85.8 | 18,716 | 25.1 | 91.8 |
| Quercus velutina | 120 | 27.1 | | 32,310 | 43.3 | |
| Other species | 63 | 14.2 | | 6,165 | 8.2 | |

[1] Based on a 20% (8 acre) strip cruise, 10 in. DBH limit.
[2] Board foot volumes (Scribner scale) are for the 8 acre sample, not entire forest.

Table 2.--Composition of Radrick Forest subtypes, based on trees 10 inches and greater in diameter at breast height, 1968.[1]

| | White Oak/Mixed Hdwd. | | Black Oak/Mixed Hdwd. | | Red-Black Oak/Red Maple | |
|---|---|---|---|---|---|---|
| Species | No. of trees | Board ft. vol./acre[2] | No. of trees | Board ft. vol./acre | No. of trees | Board ft. vol./acre |
| *Quercus rubra* | 4 | 537 | 6 | 1,844 | 45 | 4,491 |
| *Quercus alba* | 109 | 4,451 | 25 | 2,936 | 50 | 1,620 |
| *Quercus velutina* | 35 | 3,159 | 20 | 4,928 | 65 | 6,441 |
| *Carya grabra* | 7 | 348 | 3 | 289 | 14 | 431 |
| *Acer rubrum* | - | - | - | - | 10 | 367 |
| *Prunus serotina* | 4 | 233 | 3 | 54 | 6 | 300 |
| *Ulmus americana* | 3 | 32 | 1 | 43 | | |
| *Acer saccharum* | 3 | 24 | -- | -- | 1 | 36 |
| *Juglans nigra* | 1 | 83 | 1 | 152 | 1 | 65 |
| *Carya ovata* | -- | -- | -- | -- | 1 | 65 |
| *Tilia americana* | 1 | 30 | -- | -- | | |
| *Fagus grandifolia* | -- | -- | -- | -- | 1 | 18 |

[1] Based on a 20% (8 acre) strip cruise, 10 in. DBH limit.
[2] Board foot volumes (Scribner scale) per acre are based on the proportion of the total 8 acre sample within each subtype sample.

Oak/Red Maple type is on the till portion of the study area, and probably accounts in large part for its major difference in species composition compared to the other types.

Density, Frequency, and Size Classes

While the timber strip cruise conducted in 1968 does not allow for an exact replicate survey and data comparison in 1988, the permanent plot survey does permit a comparison of each type over time. Number of trees (density), frequency with which species occurred (number of plots), and distribution by the size classes of understory (1-3.9), subdominant canopy (4-11.0) and dominant canopy (12+), in dbh are reported in Tables 3 (1968) and 4 (1988).

The dominant canopy of the forest was dominated by about the same relative density of oak species in 1968 (88%) and 1988 (82%). However, there was a decrease in the number of red (40%) and black (37%) oaks in this size class and an increase (27%) of white oak trees. This change has resulted from the death and blow-down of some mature red and black oaks and the ingrowth of white oak from the 4-11.9 class into the 12+ in dbh class.

The subdominant canopy in 1968 was characterized by white oak at the larger diameters and black cherry, American elm, red maple, sassafras (*Sassafras albidum* Nutt.), and sugar maple at various diameters. Of particular importance is the absence of black oak and the near absence of red oak in this category and the presence of maple species. The most obvious changes in the last 20 years have been the reduction in relative density of white oak (55%), sassafras (59%), American elm (39%), and the increase in sugar (44%) and red (14%) maple. Of the decrease of 24 white oak trees in this dbh class, 8 moved up into the 12+ class and 16 died. During the 1987-88 survey, 4 dead white oaks could still be identified by their bark remains. Several dead stems of sassafras and American elm were also identifiable in the plots. Concerning the increase in maples, sugar maple increased in frequency in 3 plots, and red maple decreased in 2 plots.

Table 3.--Density and frequency by size class of tree species in Radrick Forest in 1968.[1]

| Species | Understory | | Subdominant Canopy | | Dominant Canopy | | |
|---|---|---|---|---|---|---|---|
| | Density N/%[2] | Frequency N/% | Density N/% | Frequency N/% | Density N/% | Frequency N/% | Total Density N/% |
| Quercus alba | -- | -- | 44/19 | 18/72 | 30/45 | 15/60 | 74/13 |
| Quercus rubra | 6/2 | 6/24 | 2/0.9 | 1/4 | 10/15 | 6/24 | 18/3 |
| Quercus velutina | -- | -- | -- | -- | 19/28 | 14/56 | 19/3 |
| Carya glabra | 4/1 | 2/8 | 5/2 | 5/20 | 4/6 | 3/12 | 13/2 |
| Carya ovata | 11/4 | 8/32 | 6/3 | 5/20 | 1/2 | 1/4 | 18/3 |
| Prunus serotina | 23/8 | 13/52 | 39/17 | 12/48 | 2/3 | 2/8 | 64/11 |
| Juglans nigra | 1/0.3 | 1/4 | -- | -- | 1/2 | 1/4 | 2/.03 |
| Acer rubrum | 114/39 | 11/44 | 42/18 | 13/52 | -- | -- | 156/26 |
| Acer saccharum | 10/3 | 9/36 | 18/8 | 11/44 | -- | -- | 28/5 |
| Acer nigrum | 10/3 | 7/28 | 4/2 | 3/12 | -- | -- | 14/2 |
| Ulmus americana | 23/8 | 13/52 | 31/13 | 15/60 | -- | -- | 54/9 |
| Sassafras albidum | 17/6 | 7/28 | 29/12 | 8/32 | -- | -- | 46/8 |
| Ostrya virginiana | 37/13 | 12/48 | 3/1 | 3/12 | -- | -- | 40/7 |
| Tilia americana | 11/4 | 7/28 | 4/2 | 4/16 | -- | -- | 15/3 |
| Fraxinus americana | 6/2 | 2/8 | 6/3 | 5/20 | -- | -- | 12/2 |
| Carya cordiformis | 8/3 | 6/24 | -- | -- | -- | -- | 8/1 |
| Cornus florida | 6/2 | 4/16 | -- | -- | -- | -- | 6/1 |
| Amelanchier sp. | 2/0.7 | 1/4 | -- | -- | -- | -- | 2/0.3 |
| Crataegus spp. | 2/0.7 | 2/8 | 1/0.4 | 1/4 | -- | -- | 3/0.5 |

[1] Based on 25 plots, 10 x 20 meters.
[2] Numbers to right of slash bars are relative densities and frequencies, expressed as percentages within each size class sample.

Table 4. Density, frequency, and size class of tree species in Radrick Forest in 1988.[1]

| Species | Understory | | Subdominant Canopy | | Dominant Canopy | | | |
|---|---|---|---|---|---|---|---|---|
| | Density N/%[2] | Frequency N/% | Density N/% | Frequency N/% | Density N/% | Frequency N/% | Total Density N/% | % Change Density 1968-88 |
| Quercus alba | -- | -- | 20/9 | 12/48 | 38/55 | 16/64 | 58/10 | -22 |
| Quercus rubra | 4/1 | 3/12 | -- | -- | 6/9 | 5/20 | 10/2 | -44 |
| Quercus velutina | -- | -- | -- | -- | 12/18 | 12/48 | 12/2 | -37 |
| Carya glabra | 1/0.3 | 1/4 | 4/2 | 3/12 | 4/6 | 4/16 | 9/2 | -31 |
| Carya ovata | 10/3 | 7/28 | 7/4 | 6/24 | -- | -- | 17/3 | -6 |
| Prunus serotina | 32/9 | 11/44 | 29/17 | 12/48 | 3/7 | 3/12 | 64/11 | 0 |
| Juglans nigra | -- | -- | -- | -- | 1/1 | 1/4 | 1/0.2 | -50 |
| Acer rubrum | 98/28 | 14/56 | 48/27 | 11/44 | -- | -- | 146/24 | -6 |
| Acer saccharum | 41/12 | 14/56 | 26/14 | 14/56 | 1/1 | 1/4 | 68/11 | +143 |
| Acer nigrum | 10/3 | 6/24 | 2/1 | 2/8 | -- | -- | 12/2 | -14 |
| Ulmus americana | 51/15 | 15/60 | 19/11 | 11/44 | 1/1 | 1/4 | 71/12 | +33 |
| Sassafras albidum | 3/0.9 | 3/12 | 12/7 | 7/28 | -- | -- | 15/3 | -67 |
| Ostrya virginiana | 63/18 | 15/60 | 5/2 | 4/16 | -- | -- | 68/11 | +70 |
| Tilia americana | 17/5 | 10/40 | 7/4 | 6/24 | -- | -- | 24/4 | +60 |
| Fraxinus americana | 4/1 | 3/12 | 3/2 | 3/12 | -- | -- | 7/1 | -42 |
| Carya cordiformis | 4/1 | 3/12 | -- | -- | -- | -- | 4/0.6 | -50 |
| Cornus florida | 7/2 | 4/16 | -- | -- | -- | -- | 7/1 | +17 |
| Amelanchier sp. | 1/0.3 | 1/4 | -- | -- | -- | -- | 1/0.2 | -50 |
| Crataegus spp. | 1/0.3 | 1/4 | 1/0.6 | 1/4 | -- | -- | 2/0.3 | -33 |

[1] Based on 25 plots, 10 x 20 meters.
[2] Numbers to right of slash bars are relative densities and frequencies, expressed as percentages within each size class sample.

n the understory class, red maple and hop-ornbeam (Ostrya virginiana (Mill.) K. Koch) were ost dominant in 1968, and black cherry and merican elm were frequent in over 50% of the lots sampled. During the last 20 years, density f stems increased 20%, due to the opening of the orest canopy by mortality among upper canopy oak pecies. Sugar maple increased in density by 10%, American elm by 122%, and hop-hornbeam by 0%. Sassafras showed the largest decrease in oth density and frequency.

An examination of total density (all size lasses combined) shows the major changes over he last 20 years to be a decrease in sassafras 67%), red oak (44%), white ash (Fraxinus mericana L.) (42%), black oak (37%) and pignut ickory (31%). Red maple decreased by only about %. Increasing in density were sugar maple 143%), hop hornbeam (70%), American elm (33%), nd basswood (Tilia americana L.) (Table 4).

### Reproduction of Tree Species

Sugar maple was the most common seedling in adrick Forest in 1968, in terms of both number f stems and frequency (Table 5). However, 85% f the plants were in the short ground cover lass (less than 1 ft in height). Other most ommon species, in descending order, were red aple, American elm, black cherry, and red oak. n addition, the distribution of sugar and red aple reproduction in the three forest types of he forest were quite distinct. Although sugar aple[1] occurred in all three types, 79.5% of the lants occurred in the White Oak/Mixed Hardwoods ortion of the forest. Red maple, in contrast, id not occur in the White Oak/Mixed Hardwood ype. It was primarily in the Red-Black Oak/Red aple type (91% density, 85% frequency).

The biggest change in woody ground cover uring the last 20 years has been a large ncrease in white ash seedling density (2060%) nd frequency (56%) (Table 6). White ash was resent in only 9% of the milacre plots in 1968, ompared to 65% in 1988. Most of the ash eproduction occurred in the western portion of he forest, where an adjacent 60-year old stand, ith considerable ash, serves as an ample seed ource. However, little of the white ash has dvanced into the understory and subdominant size lasses over the 20-year period (Table 4 shows a 2% decrease in density for the period). White sh can be a very transient species in the eedling class over time, due to abundant seed ears. The only other species besides white ash o increase in density since 1968 has been itternut hickory (Carya cordiformis (Wang.) K. och). The most noticeable decreases have been ed maple (92%), sassafras (100%), and black herry (64%). Red maple reproduction dropped from 244 specimens in 1968 to only 20 in 1988, and no sassafras seedlings were present in 1988. Although sugar maple and American elm are still abundant, both show density decreases of approximately 20% in 1988.

[1]Seedlings of Acer nigrum and Acer saccharum re considered together.

## DISCUSSION AND CONCLUSIONS

Radrick Forest is old-growth in the sense that it's overstory is dominated by remarkably large and old oaks relative to those of the surrounding countryside. Having been heavily cut in the late 1820s, it is not an example of true pre-settlement old-growth. However, it's overstory composition is relatively similar to the old-growth oak-hickory forests of pre-settlement time.

Overall, the successional trend is toward mesophytic species not oaks--especially sugar and black maples. American beech is totally lacking in the understory and ground cover; only one beech (16 in dbh) occurs in the entire forest. McGee (1986) and Romme and Martin (1982) report a similar pattern in successional change due to tree fall in old-growth forests. More specifically, mature black and red oak in the 20+ in diameter classes are dying, and white oak in the 4 to 10 in dbh classes are showing a rapid decline. Whereas the loss of the mature black and red oak is expected, there is less of a reason for the decline of the white oak. It may be the intolerance of white oak in this size class, due to not occupying space in the canopy. Also showing a rapid decline over the last 20 years has been sassafras, a species intolerant to low light intensity below an upper canopy.

Sugar maple (including black maple) has been the most dynamic species during the period. It has shown the most rapid increase in density, frequency, and growth (diameter) of any major tree species. It is increasing in frequency in the subdominant canopy class (27%), whereas red maple seems to be decreasing slightly (15%). Also, the larger sugar maples showed more rapid diameter growth since 1968 than did the large red maples.

It is anticipated when Radrick Forest is re-surveyed again in 20 years that most of the black oak will be gone and that red and white oak, though reduced in number, will be the dominant canopy species, particularly white oak. Sugar maple will be the dominant in the subdominant overstory, except on the till soils (Red-Black Oak/Red Maple type), where red maple will continue to increase in density and dominance. Basswood should also become more common in the understory (1-3.9 in dbh) during the next 20 years (54% increase in density over last 20 years). Beech will probably not increase appreciably during the period due to lack of seed source.

Table 5.--Reproduction of tree species in Radrick Forest, by size class and frequency of occurrence, in 1968.

| Species | Short Ground Cover N | Tall Ground Cover N | Total[1] Density N/% | Frequency[2] % |
|---|---|---|---|---|
| Acer saccharum/A. nigrum | 232 | 41 | 273/24 | 64 |
| Acer rubrum | 181 | 63 | 244/22 | 42 |
| Ulmus americana[3] | 97 | 125 | 222/20 | 42 |
| Prunus serotina | 122 | 84 | 206/18 | 49 |
| Quercus rubra | 36 | 15 | 51/6 | 27 |
| Quercus alba | 1 | 9 | 10/0.9 | 4 |
| Sassafras albidum | 11 | 31 | 42/4 | 17 |
| Carya glabra | 15 | 5 | 20/2 | 15 |
| Carya ovata | 5 | 14 | 19/2 | 15 |
| Fraxinus americana | 3 | 17 | 20/2 | 9 |
| Tilia americana | 5 | 7 | 12/1 | 10 |
| Carya cordiformis | 1 | 5 | 6/0.5 | 6 |
| Juglans nigra | -- | 1 | 1/0 | 1 |
| Morus alba | -- | 1 | 1/0 | 1 |

[1]Numbers to right of slash bars are relative densities, expressed as the proportion (%) of each species compared to the number of stems present for all species.
[2]Frequency defined as the percentage of milacre plots that a species occurred.
[3] Ulmus americana was not separated from Ulmus rubra at the seedling stage.

Table 6.--Reproduction of tree species in Radrick Forest, by size class and frequency of occurrence, in 1988.

| Species | Short Ground Cover N | Tall Ground Cover N | Total[1] Density N/% | Frequency[2] % | % Change Density, 1968-88 |
|---|---|---|---|---|---|
| Acer saccharum/A. nigrum | 61 | 156 | 217/22 | 54 | -21 |
| Acer rubrum | 10 | 10 | 20/2 | 9 | -92 |
| Ulmus americana[3] | 96 | 86 | 182/18 | 45 | -18 |
| Prunus serotina | 26 | 49 | 75/8 | 37 | -64 |
| Quercus rubra | 14 | 2 | 16/2 | 13 | -69 |
| Quercus alba | 4 | 0 | 4/0.4 | 4 | -60 |
| Sassafras albidum | -- | -- | -- | -- | -100 |
| Carya glabra | 7 | 4 | 11/1 | 9 | -45 |
| Carya ovata | 7 | 5 | 12/1 | 11 | -37 |
| Fraxinus americana | 253 | 179 | 432/44 | 65 | +2060 |
| Tilia americana | 4 | 5 | 9/1 | 6 | -25 |
| Carya cordiformis | 9 | 3 | 12/1 | 8 | +100 |
| Juglans nigra | -- | -- | -- | -- | -- |
| Morus alba | -- | -- | -- | -- | -- |
| Acer negundo | 0 | 1 | 1/0.1 | 1 | -- |

[1]Numbers to right of slash bars are relative densities, expressed as the proportion (%) of each species as compared to the number of stems present for all species.
[2]Frequency equals the percentage of milacre plots that a species occurred.
[3]Ulmus americana was not separated from Ulmus rubra at the seedling stage.

Concerning the woody ground cover, sugar and black maple are expected to continue their dominance. The role of white ash is uncertain. While a prolific reproducer, it does not seem to be recruited into the understory class in the mature oak stand.

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REDCEDAR (Juniperus virginiana L.) COMMUNITIES IN THE KENTUCKY RIVER GORGE AREA OF THE BLUEGRASS REGION OF KENTUCKY[1/]

William S. Bryant[2/]

Abstract.--Clifftop redcedar (Juniperus virginiana L.) communities in the gorges of the Kentucky River and its tributaries were studied. Average density was high (766 trees/ha), but basal area (14-18 $m^2$/ha) was lower than for nearby hardwood stands. Because of the clear dominance of redcedar (52-65% of the importance values), species diversity was low and evergreenness high. The small tree-shrub associates in these communities form a distinct and characteristic component. The harsh clifftop environments (S-, W-, SW-facing exposures; thin, clayey soils over limestone; low soil moisture; low nutrient levels) serve to reduce competition from more site-demanding species. Those factors, plus fire protection, have served to select for redcedar. The coefficients of determination and species replacement patterns indicate that these clifftop communities are rather stable and long persisting.

Keywords: Juniperus virginiana, redcedar, Kentucky

## INTRODUCTION

According to Braun (1950) the only areas of natural vegetation that remain in the Inner Bluegrass of Kentucky are confined to the gorges of the Kentucky River and its tributaries. Braun wrote that, "In these gorges communities range from the most mesophytic on deep talus of sheltered slopes to dry and open redcedar communities on exposed cliffs." Martin et al. (1979) found the mesic slope communities to have sugar maple (Acer saccharum), white ash (Fraxinus americana), northern red oak (Quercus rubra), basswood (Tilia americana) and bitternut hickory (Carya cordiformis) as the dominants, whereas on the dry, exposed slopes, the dominants were redcedar (Juniperus virginiana), chinquapin oak (Q. muehlenbergii), blue ash (F. quadrangulata), sugar maple, northern red oak, and white ash. The gorge communities are distinct and not representative of the open savanna-woodland that formerly occupied the rolling, fertile uplands away from the gorges (Braun 1950, Bryant et al. 1980, Campbell 1985).

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Figure 1.--View of a redcedar community on a clifftop in the Kentucky River gorge area.

The redcedar communities associated with the Kentucky River gorge area have long been known (fig. 1). In fact, the earliest descriptions of the Bluegrass Region made mention of the groves of redcedar that crowned the Kentucky River cliffs (McAfee 1773, Filson 1784, Morse 1789, Imlay 1792, McMurtire 1819, Flint 1822); however, since that time only a few brief accounts of these communities have appeared

Evans 1889, Harper 1912, Martin et al. 1979). hese stands are generally small in size and are omewhat scattered in their distribution. For the ost part they are dense and the open glade so rominent in other geographical areas is less well eveloped; e.g. Alabama (Mohr 1901, Harper 1920), he Nashville Basin of Tennessee (Gattinger 1901, arper 1926, Picklesimer 1927, Freeman 1933, uarterman 1950a,b), east Tennessee (Cain 1931), he Ozarks of Missouri and Arkansas (Palmer 1921, urner 1935, Steyermark 1940, Erickson et al. 1942, ucera and Martin 1957, Keeland 1978), southern hio (Braun 1928), northwestern Georgia (Van Horn 980), southern Wisconsin (Curtis 1959, Bray 1960), nd elsewhere in Kentucky (Baskin and Baskin 1975, 978, 1985, Johnson 1981). Only Picklesimer (1927), urtis (1959), Keeland (1978) and Fralish (1976) or Illinois, presented quantitative information n the redcedar component of these communities.

This paper summarizes the results of my studies f the redcedar communities on the soil borders of he exposed clifftops in the Kentucky River gorge rea of central Kentucky. Emphasis is placed on he structure and composition of these stands as ell as the apparent environmental complex operating on these clifftop habitats that may serve to elect for redcedar and its associates while reducing competition from more site-demanding hardwoods.

## The Study Area

The Bluegrass Region of Kentucky is a central owland formed on limestone of Ordovician age. It s flat to rolling except near large streams ecause it is the uplifted peneplain still in the irst stages of dissection (McFarlan 1943). Erosion as been slow and mainly by solution. The geologic istory of the Kentucky River involves uplift, bandonment of former (Pliocene) channels, rejunenation and downcutting which have created a rugged andscape with massive limestone cliffs forming he gorge. Tributaries are similarly deep, cliffbound gashes in the upland. There is a 100-125 m ifference in elevation from the tops of many of he cliffs to the current river level. The slopes re sheer drops or 50-70% slopes. Meander loops f the river account for the multitude of slope xposures.

Caves, sinks, and springs dot the uplands and unoff is through these. In places, remnants of he Irvine gravels (deposits from the abandoned hannels) and clays are common.

The soils are developed in residuum or colluvum from the limestone. These soils are shallow, zonal with a high clay and rock content. Their water-holding capacity is low. The process of oil formation on the clifftops is similar to that or the glades of the Nashville Basin (Galloway 19).

The climate of the Bluegrass Region is of the humid continental type, with sharp contrasts etween the winter and summer. The average temperature for the region is 12.8 C (Palmquist and Hall 1961). Rainfall averages 109 cm annually for the Bluegrass. The annual runoff is 38 cm and the discharge by evapotranspiration is about 71 cm (Hendrickson and Kreiger 1964). Although precipitation is rather evenly distributed throughout the year, drought conditions occasionally prevail for several weeks during the summer (Palmquist and Hall 1961).

## METHODS

Redcedar communities on the Kentucky River cliffs in Anderson, Fayette, Franklin, Jessamine, Madison, Mercer, and Woodford counties were located. Some grazing and logging had occurred in the past in a number of these stands. Only the least disturbed stands are presented for analysis here.

Trees were sampled in 0.04 ha circular plots spaced at 30 m intervals throughout the stands. Trees were those woody species with diameters at breast height (dbh) of $\geq$8.9 cm (3.5 inches).

Seedlings were sampled in 0.004 ha circular plots and saplings in 0.01 ha circular plots. Size classes follow Bryant (1978). Class 1 seedlings ranged from $\geq$15.2 cm to <1.37 m (6 inches - 4.5 feet) in height. All other seedlings and saplings were >1.37 m in height. Class 2 seedlings <1.27 cm (0.5 inch) diameter at ground level. Diameter ranges for Class 3 saplings were >1.27 <3.81 cm (0.5 <1.5 inches); Class 4, >3.81 <6.35 cm (1.5 <2.5 inches); and Class 5, >6.35<8.9 cm (2.5 <3.5 inches). Shrubs were sampled with with seedlings and saplings.

Trees were analyzed to relative frequency (RF), relative density (RD), and relative dominance (RDo) which were summed to give an importance value (IV) for each species. Density (trees/ha) and basal area ($m^2$/ha) were determined. The coefficients of similarity between stands were determined by the equation: C = (2w)/(a+b), where a = the sum of importance values of all species in one stand, b = a similar sum for a second stand, and w = the sum of lesser values for only those species which are in common to the two stands.

Species diversity patterns were calculated using the Shannon-Wiener index:

$$H' = -\sum_{i=1}^{s} pi \log_2 pi,$$

where s is the number of species and pi is the proportion of each species in the forest (Shannon and Weaver 1949). The evergreen character of a stand was expressed as the sum of importance values of all evergreen species divided by the sum of importance values of all species (Monk 1965, 1966).

Stem counts were plotted against their size classes on semi-log paper and a regression line was fitted to the plotted data using the methods of Schmelz and Lindsey (1965). The coefficient of determination ($100r^2$), which defines how much the variation of the dependent variable (density) is accounted for by the variation of the independent

variable (diameter), was used as an index of the degree of past disturbance of the stand structure still detectable at the time of study, a high value indicating little disturbance (Schmelz and Lindsey 1965).

For a limited number of stands, soil cores were taken on a seasonal basis. These soils were sent to the University of Kentucky Soil Testing Laboratory for analysis of pH, organic matter(%), soil moisture (%), Ca, P, K, and Mg.

## RESULTS

Eastern redcedar (IV 174.65) clearly dominates the soil borders on the exposed limestone cliffs in the Kentucky River gorge area (table 1). In those stands sampled, the frequency of redcedar was 100% and it accounted for ≈76% of the density and ≈79% of the basal area. Its major associates were white ash (F. americana, IV 42.07), redbud (Cercis canadensis, IV 17.02), slippery elm (Ulmus rubra, IV 14.79), honey locust (Gleditsia triacanthos, IV 10.71), and chinquapin oak (Q. muehlenbergii, IV 6.33). Overall tree density averaged 766 trees/ha and basal area ranged from 13.7-18.3 $m^2$/ha.

Because of the dominance of redcedar, species diversity (H') was low, ranging from 1.2-1.7, relative to hardwood stands in the gorge. The degree of evergreenness, 52%-65%, was also an indication of the dominance of redcedar. Although there was some variability among stands, the average similarity was 75%.

The coefficients of determination ($100r^2$) for the three least disturbed stands were 97, 96, and 94. Some trees were >120 years old, however, most of those that were cored for age analysis were ≈90 years.

There were 19 species of tree seedlings/saplings in the plots, but individuals of only 5 species, redcedar, chinquapin oak, slippery elm, redbud, and hackberry (Celtis occidentalis) reached tree-replacement size (table 2). This varied among stands with redcedar and redbud being the only species with numbers that seemed significant. Openings in the woodland, many created by windthrow, were frequent enough to allow the establishment of redcedar seedlings/saplings. Many of the other tree species represented here are pioneer or early successional species and usually fail to reach the tree stratum.

The species of the small tree and shrub stratum consisted of redbud, fragrant sumac (Rhus aromatica), Carolina buckthorn (Rhamnus caroliniana), lanceleaf buckthorn (R. lanceolata), blackhaw viburnum (Viburnum rufidulum), roughleaf dogwood (Cornus drummondi), coralberry (Symphoricarpos orbiculatus), and Carolina rose (Rosa carolina). The dwarf hackberry (Celtis tenuifolia), wafer ash (Ptelea trifoliata), ninebark (Physocarpus opulifolius), and prickly ash (Zanthoxylum americana)

Table 1.--The average importance values (IV) for three of the largest and least disturbed stands of redcedar in the Kentucky River gorge area.

| Species | IV |
|---|---|
| Juniperus virginiana | 174.65 |
| Fraxinus americana | 42.07 |
| Cercis canadensis | 17.02 |
| Ulmus rubra | 14.79 |
| Gleditsia triacanthos | 10.71 |
| Quercus muehlenbergii | 6.33 |
| Diospyros virginiana | 5.16 |
| Acer saccharum | 5.11 |
| Robinia pseudoacacia | 4.55 |
| Celtis occidentalis | 3.91 |
| Quercus rubra | 2.25 |
| Juglans nigra | 2.14 |
| Sassafras albidum | 2.10 |
| Prunus serotina | 2.03 |
| Morus rubra | 1.74 |
| Viburnum rufidulum | 1.61 |
| Aesculus glabra | 1.27 |
| Fraxinus quadrangulata | 1.15 |
| Quercus stellata | 0.85 |
| Carya glabra | 0.55 |

were occasional and generally few in numbers. These twelve species are here considered to be characteristic of the redcedar communities of the Kentucky River clifftops. As many as seven of these species were present together in some stands. Table 3 summarizes the size class distributions of the small tree and shrub stratum. The presence of two introduced species, Lonicera and Ligustrum, is a remnant of some past disturbance.

Table 2.--Size class distribution of seedlings (Class 1 & 2) and saplings (Classes 3, 4, & 5) per hectare in the redcedar communities of the Kentucky River gorge area.

| Size Classes | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Juniperus virginiana | 518.7 | 127.6 | 333.5 | 227.2 | 46.1 |
| Cercis canadensis | 325.2 | 185.3 | 77.4 | 11.5 | 9.9 |
| Fraxinus americana | 592.8 | 172.9 | 133.4 | 0 | 4.9 |
| Quercus muehlenbergii | 279.9 | 8.2 | 0 | 4.9 | 3.3 |
| Ulmus rubra | 119.3 | 0 | 21.4 | 0 | 4.9 |
| Celtis occidentalis[3/] | 148.2 | 0 | 41.2 | 19.8 | 4.9 |
| Prunus serotina | 16.5 | 0 | 0 | 3.3 | 0 |
| Acer saccharum | 24.7 | 16.5 | 4.9 | 3.3 | 0 |
| Acer negundo | 28.8 | 0 | 4.9 | 0 | 0 |
| Diospyros virginiana | 24.7 | 24.7 | 0 | 0 | 0 |
| Gleditsia triacanthos | 16.5 | 0 | 0 | 0 | 0 |
| Morus rubra | 32.9 | 0 | 16.5 | 0 | 0 |
| Juglans nigra | 41.2 | 0 | 0 | 0 | 0 |
| Liriodendron tulipifera | 16.5 | 0 | 0 | 0 | 0 |
| Fraxinus quadrangulata | 12.4 | 0 | 0 | 0 | 0 |
| Sassafras albidum | 74.1 | 0 | 0 | 0 | 0 |
| Robinia pseudoacacia | 12.4 | 0 | 0 | 0 | 0 |
| Carya glabra | 16.5 | 0 | 0 | 0 | 0 |
| Quercus rubra | 8.2 | 0 | 0 | 0 | 0 |
| Totals | 2309.5 | 535.2 | 633.2 | 274.9 | 74.0 |

[1/] May include Celtis tenuifolia.

Table 3.--Size class distribution of seedlings (Class 1 & 2) and saplings (Classes 3,4 & 5) of shrubs/hectare in the redcedar communities of the Kentucky River gorge area.

| Size Classes | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Rhus aromatica | 2091.3 | 551.6 | 42.8 | 0 | 0 |
| Rhamnus caroliniana | 1671.4 | 185.3 | 126.8 | 8.2 | 0 |
| Rhamnus lanceolata | 284.1 | 0 | 0 | 0 | 0 |
| Symphoricarpos orbiculatus | 1564.3 | 0 | 0 | 0 | 0 |
| Cornus drummondi | 222.3 | 49.4 | 6.6 | 0 | 0 |
| Viburnum rufidulum | 160.6 | 82.3 | 13.2 | 6.6 | 0 |
| Rubus sp. | 370.5 | 0 | 0 | 0 | 0 |
| Rosa carolina | 45.3 | 0 | 0 | 0 | 0 |
| Euonymus atropurpureus | 12.4 | 0 | 0 | 0 | 0 |
| Celastrus scandens | 37.1 | 0 | 0 | 0 | 0 |
| Lonicera tartarica | 12.4 | 24.7 | 9.9 | 0 | 0 |
| Ligustrum sp. | 65.9 | 12.4 | 0 | 0 | 0 |
| Totals | 6537.6 | 905.7 | 199.3 | 14.8 | 0 |

Soil properties varied somewhat among stands and seasonally within stands. Table 4 summarizes these properties. In general, P was significantly lower and Ca significantly higher in certain redcedar stands than for adjacent hardwood communities (table 4). Soil depth ranged from 0 cm on exposed outcrops to 50 cm, and averaged about 20 cm.

Table 4.--A comparison of the seasonal range of plant nutrients (P,K,Ca, and Mg in ppm), pH, organic matter (%), and soil moisture (%) between a redcedar community and a deciduous hardwood community on a N-facing slope in the Kentucky River gorge area.

| | Redcedar Community | N-facing Slope |
|---|---|---|
| P[4/] | 1-5 ppm | 111.5-150 ppm |
| K | 111-137 ppm | 129.0-192 ppm |
| Ca[5/] | 4375-5875 ppm | 3250-4575 ppm |
| Mg[6/] | 101.5-163.5 ppm | 154-179.5 ppm |
| pH | 7.4-7.8 | 6.4-7.5 |
| Organic Matter | 7.2-8.9% | 7.1-7.9% |
| Soil Moisture | 31-38% | 35-53% |

4/ (P<0.001) t-test
5/ (P<0.01) t-test
6/ ()<0.05) t-test

## DISCUSSION

Although eastern redcedar (Juniperus virginiana) is a common tree in old field communities over much of eastern United States, in many parts of its range, especially limestone outcrop areas of the Interior Low Plateaus and the Limestone Valleys and Uplands Soils Province (Bennett 1921), it forms long persistant stable communities. These communities have been regarded as climax (Picklesimer 1927), subclimax (Freeman 1933, Quarterman 1950a,b, Steyermark 1940), and edaphic climax (Erickson et al. 1942). In addition, stable redcedar communities occur along the Mississippi River from Missouri to Minnesota (Curtis 1959) and in the Great Valley Province (Carr 1944, Braun 1950). However, in those areas where redcedar forms stable communities, most of the ecological work has centered on the open, rocky herb-dominated glade rather than the redcedar woodland. As a consequence, less is known about the structure, dynamics, and environmental relationships of the redcedar woodland communities.

Historically, redcedar has long been known as a major species on the Kentucky River cliffs of central Kentucky where it occurs on the soil borders of exposed clifftops and ledges. These are long persistant stands which suggest climax, probably edaphic climax. On similar sites in southern Illinois, Winterringer and Vestal (1956) considered the small tree-shrub communities on the soil borders of exposed sandstone cliffs to be climax. The high coefficients of determination (Schmelz and Lindsey 1965) and the replacement patterns shown by redcedar suggest that these are relatively stable communities.

Many writers have considered the characteristic habitat for redcedar to be shallow limestone soils on rough topography. The characteristic habitats for members of the shrub and small tree component, Rhus aromatica, Rhamnus caroliniana, R. lanceolata, Cercis canadensis, Viburnum rufidulum, Ptelea trifoliata, Cornus drummondi, Celtis tenuifolia, Zanthoxylum americana, Ceanothus americanus, and Physocarpus opulifolius, include "bluff escarpments, limestone glades, rocky open wooded slopes, borders of glades" (Steyermark 1964). In the Kentucky River area, V. rufidulum, P. trifoliata, and C. tenuifolia, occur as disjunct populations (Little 1977). The ranges of many of the other shrubs extend just into central Kentucky where they overlap in the gorge.

According to McDougal (1949) some plants "tolerate" rather than "prefer" certain habitats. This means that, under ordinary conditions, they are not able to compete with other plants in more favorable habitats, but are able to meet competition in unfavorable ones. Redcedar appears to be such a species. It shows best growth on the better soils, but on these is unable to compete with succeeding hardwoods (Fowells 1965). On the dry, infertile limestone outcrops it forms stable communities and the environmental complex that develops on these sites selects against potential competitors. In the redcedar-hardwood stands in the Central Basin of Tennessee, McKinney and Hemmerly (1984) considered white ash to be a successional species. On the Kentucky River clifftops, white ash showed slight increases in importance with increasing P, soil moisture, and organic matter. However, it is doubtful that white ash will displace redcedar in the clifftop communities.

The factor or factor complex that is responsible for the maintenance of redcedar communities has not been determined (Curtis 1959, Massey 1968). It seems probable that a number of factors, either singly or in combination, interact to produce an environmental complex that may select for redcedar

in this harsh environment. These factors include shallow, azonal clayey soil; limestone, often dolomitic, bedrock that funnels off water through subterranean passageways resulting in reduced soil moisture; pH >7; limited or excessive plant nutrients; limited organic matter; great exposure to wind and sunlight; and protection from fire.

> Beadle (1953) wrote that, "Soil properties can affect vegetation in two ways: firstly, by controlling structure. Floristic composition is controlled by selection of species suitable to the area. Plants that have become adapted to low nutrient levels are capable of surviving in the low nutrient media, while those with higher requirements are excluded. Selection may occur at the germination stage, or more frequently in the early stages of the seedling, or even at the near-maturity stage through competition. On the other hand, community structure is determined partly by the habit of the species that succeed in the area, partly by the relative levels of the various plant nutrients (including water) which determine the size attained by the individual plants, and partly by the manner in which the various species have become adapted to the limited factor of the environment. Consequently, in some areas of uniform climate and physiography distinct patterns of vegetation develop, which are determined by the concentration of the limiting nutrient."

Based on observations in the Kentucky River gorge area, it appears that a situation similar to Beadle's predictions may be occurring. However, there are a number of problems in determining the relationship of soil chemical properties and forest trees because of the lack of information on forest tree requirements, forest tree-forest soil interrelationships, and confusion of methodology in forest soil analysis (Gessel 1962). This is further compounded by the fact that the total of a nutrient in the soil may be determined with great accuracy, yet its availability is susceptible to little more than a rough approximation (Buckman and Brady 1969).

The soils of the Inner Bluegrass are known for their great fertility, largely attributable to their unusually high P content (McFarlan 1943). However, the P content in the soils of some of the redcedar stands was significantly lower than for adjacent hardwood sites. Low P levels are known to influence the distribution of evergreen or sclerophyllous vegetation (Billings 1950, Beadle 1954, 1966, Wright and Mooney 1965). Monk (1965, 1966) found evergreen species in Florida to be most abundant on soils low in Ca, K, P, and N, while Westman (1975) found P to be low in the pygmy forest of California. Goldberg (1983) equated nutrient-poor soils and evergreenness.

pH influences nutrient absorption and plant growth especially by its influence on nutrient availability. P, which is never readily soluble in soil, seems to be held with less tenacity in a pH centering around 6.5, thus plants are able to extract it with less difficulty (Buckman and Brady 1969). The soil pH on the clifftops was generally >7. In the adjacent hardwood slope communties, the pH was in the 6.5 range although this was variable.

Redcedar and many of its tree and shrub associates are calciophilous species. Calcium was significantly higher in the soils under the redcedars than in the surrounding hardwood stands. Buckman and Brady (1969) noted that excess calcium carbonate may have a detrimental influence on plants by reducing phosphate availability through the formation of complex and insoluble calcium phosphates. Fletcher and Ochrymochych (1955) however, found that an increase in exchangeable soil calcium leads to increased root development in redcedar seedlings resulting in greater nutrient uptake, especially P.

Other nutrients, organic matter, and their interactions may exert influence on the plant community, but the combination of low P, high Ca, and pH >7 may favor redcedar. It is this combination of factors that is found in the redcedar communities of Arkansas (Keeland 1978), Missouri (Fletcher and Ochrymochych 1955), Tennessee (Turner 1972), and Wisconsin (Curtis 1959). The differentiating effects of parent material are greatest on immature soils which may be chemically unbalanced or deficient (Lutz and Chandler 1946).

Limited soil moisture, the result of rapid underground drainage and high evaporation, has been cited most often as controlling cedar glades (Freeman 1933, Quarterman 1950a,b, Erickson et al. 1942, Bray 1960). Total soil moisture was lower in the redcedar communities than in adjacent hardwood communities. This may be attributed to drainage and evaporation, but also to the shallow, clayey soils. The clay dries hard and develops cracks during periods of drought, but during rainy periods the clay swells and the cracks close. The result is that the water stands on the soil surface where it is unavailable to plants. Erickson et al. (1942) considered standing water to cause winter rotting in the Missouri glades. This might serve to eliminate potential competitors. Also, the short periods of drought may be more disastrous on the clifftops than longer periods in less severe habitats. Quarterman (1950a) found a rapid water loss from saturation levels to near zero in two or three day periods in the cedar glades of the Nashville Basin.

The nature of the limestone bedrock may also influence the establishment and distribution of redcedar communities. The nutrients released through weathering have already been mentioned. The denseness of the bedrock poses problems for root penetration and in some areas limits this to cracks and crevices. Since the bedrock is dotted with sinks, it also serves to funnel off much of the water underground. The heating action of the limestone adds to the xeric conditions (Dansureau 1957).

In all of the stable redcedar communities, the soils are shallow and azonal which poses problems for the anchorage of large trees. The seedlings of many species possess deep penetrating taproots, however, because of the thin soil and dense bedrock, a lateral taproot may be essential if trees are to successfully occupy these outcrops. Redcedar has a penetrating taproot in the seedling stage and in later stages may develop a lateral taproot system. This was observed in a number of overturned trees and a similar condition was reported by Winterringer and Vestal (1956) on the xeric sandstone cliffs in Illinois.

The clay soils may also present a barrier to root growth. The soils of the Missouri glades were clayey and droughty (Kucera and Martin 1957). In addition to the residual clays, deposits of the high terrace clays are local along the Kentucky River uplands. These clays have been used in pottery production, thus the baking action of the sun on them may be critical.

The position of these redcedar communities atop the S-, W-, and SW-facing slopes may exaggerate the effects of temperature and evaporation. During the summer, day time air temperatures may be as much as 8 C higher in the redcedar communities than in less exposed hardwood sites. Exposure must be critical because hardwoods dominate the N-, E-, and NE-facing slopes. There redcedar is absent or of only minor importance.

Windthrow may also be related to exposure and shallow soils. The periodic opening of the stands by blow downs undoubtedly favors redcedar as does the high light intensity on the exposed clifftops. Harper (1912) did not feel that the denseness of certain redcedar stands should be viewed as one preventing reproduction and seedling development. More recent studies (Lassoie et al. 1983) have found redcedar to persist under an oak-hickory canopy which may suggest that it is not as intolerant as generally accepted.

The absence of fires is another factor that must be considered in the maintenance of stable redcedar communities. In fact, Harper (1912) suggested that "redcedar dreads fire more than it likes lime". Curtis (1959) considered some form of fire barrier, especially from the southwest, as an essential feature of those sites where redcedar is old-growth. Prior to and at the time of settlement of the Bluegrass Region, fire was of common occurrence (Roosevelt 1900). Perhaps the upper slopes and clifftops in the Kentucky River gorge served as refugia for redcedar and its associates. Nigh et al. (1985) referred to those sites in the River Hills of Missouri where redcedar and sugar maple were associates as fire refugia. Fralish (1988) supports the refugia view in southern Illinois. Conditions such as rocky, shallow soils and low fuel loads do not promote fires (Arend 1950). However, with the cessation of fires and the changes in land use that accompanied settlement, redcedar spread from its confines on the clifftops onto the rolling uplands where it has assumed a successional role. Hall (1952) reasoned that this was the way that redcedar spread and Beilmann and Brenner (1951) reported a similar situation for the Ozarks.

The success of redcedar on these limestone outcrops also involves those ecomorphological and ecophysiological adaptations that give it an advantage over hardwoods. At least three such interconnected adaptations are drought tolerance, evergreenness, and mineral conservation.

Whittaker (1975) stated that plant communities on limestone are often more xeric, or drought-adapted, than those on other substrates. This is paralleled by Wells (1976) who stated that, "The most likely places for the evolution of the more extreme xeromorphic characters under humid conditions would have been on sunny scarps with bedrock outcrops..". The drought-tolerance of redcedar is well-known (Ormsbee et al. 1976). One character associated with that tolerance is its double-membraned tonoplast (Parker 1971). The scale-like evergreen leaves of redcedar represent a xeromorphic adaptation (Harper 1912) and Monk (1966) regarded evergreen leaves as sclerophylls.

A number of metabolic adaptations of redcedar may be related to its evergreenness. In the old fields of Illinois, Ormsbee et al. (1976) found redcedar to show active photosynthesis under low soil moisture in the summer and the ability to photosynthesize during the winter even at 0 C. Because of these attributes, redcedar individuals prolong their effective growing season to essentially the entire year.

> In Florida, Monk (1965) pointed out that, "An evergreen species might have selective advantages over deciduous species in sterile soils. If a soil has a limited amount of nutrients, a community might be assembled, through natural selection, which would then to be more conservative. Although many evergreen species are tolerant to low nutrient levels, it is possible that this fact is secondary. Perhaps the cardinal point is the gradual return of nutrients to the soil through slow year-round-leaf-fall. This implies that an assemblage of evergreen species on sterile sites is a product of natural selection permitting a nearly closed cycle to exist."

Stable redcedar communities occur as small "evergreen islands" scattered throughout the eastern deciduous forest. More detailed experiments are needed to sort out those factors that determine the structure and composition of the vegetation of such "insular sites".

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DYNAMICS OF THE SUGAR MAPLE COMPONENT OF

A WHITE OAK - YELLOW-POPLAR COMMUNITY[1]

Richard C. Schlesinger[2]

Abstract.--The sugar maple (Acer saccharum Marsh) component in a southern Illinois forest increased over a 48-year period. By 1983 sugar maple was three times greater in importance than any other species in the stand. If the observed rate of increase were to continue, sugar maple would exclude all other species within another 50 to 60 years.

## INTRODUCTION

A notable phenomenon in many central hardwood forests is an increase in the importance of sugar maple (Acer saccharum Marsh.) during the last half century. This increase has been documented by a number of researchers (Anderson and Adams 1978; Boggess and Bailey 1964; McGee 1986; Newman and Ebinger 1985; Nigh et. al. 1985a and 1985b; Parker et. al. 1985; Schlesinger 1976) and has been ascribed variously to more mesic climatic conditions, exclusion of fire from the forests, and progression of the forests toward their "natural" climax.

In central hardwood forests with predominantly oak overstories, sugar maple is not generally believed to be the primary climax component. Thus, the question arises whether observed increases in the importance of sugar maple will continue. The purpose of this paper is to present and discuss the information from one stand especially as it relates to the perpetuation of the maple "wave" in the future.

## BACKGROUND

The stand we studied is located in the unglaciated hill country (Shawnee Hills Division) of southeastern Illinois (latitude 37.5 degrees N, longitude 88.3 degrees W). This stand was classified by Braun (1950 p. 137) as a typical example of the white oak (Quercus alba L.) - yellow-poplar (Liriodendron tulipifera L.) community. The development of the stand from 1935 to 1973 was reported previously (Schlesinger 1976). This paper presents the results after an additional 10 years of growth and development.

The soils are a mixture of weathered bedrock (limestones and sandstones) and loess. The primary series are Alford (fine-silty, mixed, mesic Typic Hapludalf) and Baxter (clayey, mixed, mesic Typic Paleudult). The climate is continental, with hot summers and cool winters. The annual precipitation averages 112 cm with about 60 percent occurring during the growing season from April through September. Although the precipitation is generally well distributed throughout the year, a 2- to 3-week dry period during the growing season is common.

The study area has been protected from grazing and fire since it was acquired by the USDA Forest Service in 1933. Also, no timber harvesting or silvicultural work has been done in the area. Increment core data show an abrupt increase in diameter growth rates starting in 1880 and again in 1910. Because that period coincides with the rapid expansion of the Nation's railroads and because many of the oldest trees are yellow-poplar or hickory, it is possible that a selective harvest of oaks, which were favored for railroad ties, may have been made during that time.

## METHODS

Eight permanent plots were established in 1935 near the center of the 7.4 ha stand. Within each 0.101-ha plot, each tree 4 cm dbh (diameter breast height) and larger was measured and permanently tagged. Stems less than 4 cm dbh were identified, mapped, and their heights recorded on four 4 sq m (1 milacre) subplots located in the corners of the main plots. The plots were remeasured in 1940, 1958, 1965, 1973, 1978, and 1983, at which times trees growing into the 4-cm diameter class were measured and tagged. Tree heights were measured in 1935, 1958, and 1978. Map coordinates were

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determined for the individual trees following the 1973 inventory and for ingrowth trees at the 1978 and 1983 remeasurements.

The changes in the stand during the 48-year period were examined using the traditional measures of density and basal area plus stocking percent, a measure of relative density or crowding that combines tree numbers and sizes. The tree area ratio concept (Chisman and Schumacher 1940), minimum tree area equations (Gingrich 1967), and average maximum competition levels (Ernst and Knapp 1985), collectively are used to define 100 percent stocking. The minimum tree area equation for oaks and hickories is from Gingrich (1967); equations for other species are from Stout and Nyland (1986).

The sugar maple[1] component was segregated into nine groups, based on three dbh size classes in 1935 (4 to 9.9 cm, 10 to 19.9 cm, and 20 to 29.9 cm) plus the six ingrowth groups (all less than 9.9 cm at the time first measured) from the remeasurements. Each group was evaluated for mortality, net growth, and surviver growth for each period between remeasurements. The sugar maple component was further examined in relation to the changes in the community during the 48-year period of observation.

To examine the potential for maples to occupy canopy gaps that occur when overstory trees die, the maps for each plot giving the tree locations were divided into 35 areas of equal size. Each of these subareas was 28.9 sq m, approximating the minimum tree area of a 30-cm-dbh sugar maple. The presence of overstory trees alive in 1983, overstory trees that died between 1978 and 1983, and all sugar maples were determined for each area.

## RESULTS AND DISCUSSION

The overall changes in stand structure during the study period indicate that the stand was recovering from past disturbance (fig. 1). The total number of trees declined between 1935 and 1940, increased gradually until 1965, and again declined through the last measurement. Stand basal area increased from 22.7 sq m per ha in 1935 to a high of 32.8 in 1978, declining slightly to 31.3 by 1983. The stocking rose from 76.2 percent in 1935 to 100.8 percent in 1978, and then dropped to 94.6 percent by 1983.

The changes for the various species during the 48-year period followed five different patterns. Sugar maple, white ash (Fraxinus americana L.), ironwood (Ostrya virginiana (Mill.) K. Koch) and beech (Fagus grandifolia Ehrh.) all increased in numbers, basal area, and stocking (table 1). By 1983, 51.6 percent of the trees were sugar maples, accounting for 15.4 percent of the total basal

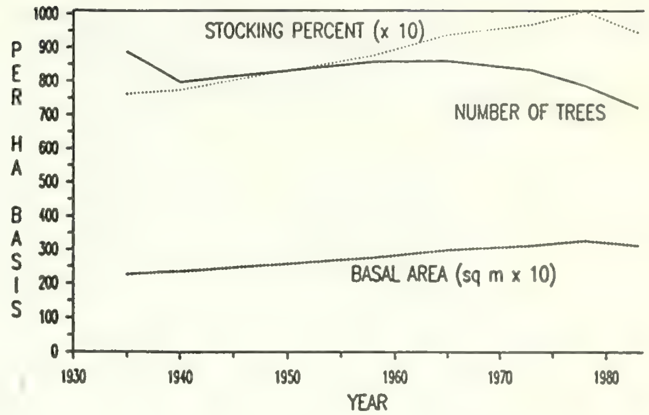


Figure 1.--Stand changes in the total (per ha) number of trees, basal area, and stocking percent from 1935 to 1983.

area, and 21.6 percent of the stocking. Together, the four species composed 71.3 percent of the trees, 18.4 percent of the basal area, and 26.0 percent of the stocking.

The two "characteristic" species, yellow-poplar and white oak, plus black oak (Q. velutina Lam.) and northern red oak (Q. rubra L.) all decreased in numbers, comprising only 12.3 percent of the total number in 1983. Collectively, their basal area increased to 57.5 percent of the stand, and their stocking percent to 44.7 percent.

Scarlet oak (Q. coccinea Muench.) and shagbark hickory (Carya ovata (Mill.) K. Koch) decreased in both numbers and stocking percent, but gained slightly in basal area; while slippery elm (Ulmus rubra Muhl.) increased in numbers, but decreased in both basal area and stocking percent. These species made up 3.5 percent of the trees, 11.2 percent of the basal area, and 11.2 percent of the stocking.

The remaining species all decreased in numbers, basal area, and stocking, and composed 13.0 percent, 12.9 percent, and 12.7 percent of the trees, basal area, and stocking, respectively, in 1983. This group included several overstory species, black gum (Nyssa sylvatica Marsh.), black walnut (Juglans nigra L.), red maple (A. rubrum L.), mockernut hickory (C. tomentosa (Poir.) Nutt.), and pignut hickory (C. glabra (Mill.) Sweet), plus flowering dogwood (Cornus florida L.), sassafras (Sassafras albidum (Nutt.) Ness), and the group of miscellaneous minor species.

The tolerance and persistence of sugar maple could lead to its dominance by allowing it to become established and grow in the understory so that it can take advantage of canopy openings created by the death of overstory trees. There is evidence for these characteristics from the plot records.

[1]The "sugar maple" group included some Florida maple (Acer barbatum Michx.) and black maple (A. nigrum Michx.) as well as putative double and triple hybrids between the three maple species.

Table 1.--Present stand and changes since 1935.

| | Numbers | | Basal area | | Stocking | | Importance | |
|---|---|---|---|---|---|---|---|---|
| | 1983 | Change | 1983 | Change | 1983 | Change | 1935 | 1983 |
| | --(per ha)-- | | --(sq m)-- | | --(percent)-- | | --(IV-200)- | |
| Sugar maple | 373.1 | 218.7 | 4.81 | 3.80 | 21.59 | 16.80 | 21.9 | 67.0 |
| Black gum | 39.5 | -18.5 | 1.67 | -.37 | 4.50 | -1.24 | 15.6 | 10.8 |
| Yellow-poplar | 19.8 | -3.7 | 6.45 | 2.81 | 7.60 | 2.68 | 18.7 | 23.3 |
| White ash | 71.7 | 59.3 | .42 | .34 | 1.96 | 1.63 | 1.7 | 11.2 |
| Black walnut | 0.0 | -6.2 | 0.0 | -.13 | 0.0 | -.44 | 1.3 | 0.0 |
| White oak | 39.5 | -71.7 | 5.54 | 2.12 | 17.94 | 5.03 | 27.6 | 23.2 |
| Scarlet oak | 12.4 | -27.2 | 2.87 | .27 | 9.01 | -.41 | 15.9 | 10.9 |
| Black oak | 23.5 | -29.7 | 5.04 | 2.16 | 15.98 | 5.30 | 18.7 | 19.3 |
| Red oak | 6.2 | -11.1 | .98 | .33 | 3.18 | .60 | 4.8 | 4.0 |
| Red maple | 0.0 | -21.0 | 0.0 | -.28 | 0.0 | -1.04 | 3.6 | 0.0 |
| Shagbark hic. | 6.2 | -23.5 | .59 | .07 | 1.99 | -.14 | 5.6 | 2.7 |
| Mockernut hic. | 9.9 | -21.0 | .89 | -.46 | 3.13 | -1.80 | 9.5 | 4.2 |
| Pignut hic. | 13.6 | -42.0 | 1.30 | 0.0 | 4.27 | -.71 | 12.0 | 6.0 |
| Slippery elm | 6.2 | 2.5 | .03 | -.03 | .16 | -.04 | 0.7 | 1.0 |
| Ironwood | 58.1 | 44.5 | .23 | .14 | 1.19 | .77 | 1.9 | 8.8 |
| Dogwood | 27.2 | -148.3 | .16 | -1.33 | .78 | -5.54 | 26.3 | 4.3 |
| Sassafras | 0.0 | -71.7 | 0.0 | -.96 | 0.0 | -3.77 | 12.3 | 0.0 |
| Beech | 12.4 | 7.4 | .30 | .20 | 1.29 | .85 | 1.0 | 2.7 |
| Other[1] | 3.7 | -2.5 | .01 | -.03 | .06 | -.11 | 0.9 | 0.6 |

[1]Includes the following species: redbud (Cercis canadensis L.), service berry (Amerlanchier arborea Michx.f.), persimmon (Diospyros virginiana L.), juniper (Juniperus communis L.), and eastern red cedar (J. virginiana L.).

In 1935, the sugar maple component ranked third in importance (IV-200, based on relative number of trees and relative basal area) behind white oak and dogwood (table 1). Its importance value of 21.9 was less than half the combined importance of white oak and yellow-poplar (46.3). The importance of sugar maple increased steadily throughout the 48-year period, ranking first by 1958. In 1983, its importance value of 67.0 was more than 40 percent larger than the combined importance of white oak and yellow-poplar (46.5).

Even when the number of sugar maple trees was no longer increasing, ingrowth continued over the study period (table 2). There were about 20 new stems per ha in 1978 and 24 in 1983, almost as

Table 2.--Sugar maple groups[1] - number of trees per hectare.

| Year | Status | L-35 | M-35 | S-35 | S-40 | S-58 | S-65 | S-73 | S-78 | S-83 | All |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1935 | alive | 8.6 | 17.3 | 128.5 | | | | | | | 154.4 |
| 1940 | alive | 8.6 | 17.3 | 126.0 | 27.2 | | | | | | 179.1 |
| | dead | | | 2.5 | | | | | | | 2.5 |
| 1958 | alive | 8.6 | 17.3 | 113.7 | 27.2 | 169.3 | | | | | 336.1 |
| | dead | | | 12.4 | | | | | | | 12.4 |
| 1965 | alive | 8.6 | 17.3 | 105.0 | 25.9 | 160.6 | 29.7 | | | | 347.2 |
| | dead | | | 8.6 | 1.2 | 8.6 | | | | | 18.5 |
| 1973 | alive | 8.6 | 17.3 | 97.6 | 24.7 | 149.5 | 27.2 | 45.7 | | | 370.7 |
| | dead | | | 7.4 | 1.2 | 11.1 | 2.5 | | | | 22.2 |
| 1978 | alive | 8.6 | 17.3 | 91.4 | 23.5 | 143.3 | 27.2 | 45.7 | 19.8 | | 376.8 |
| | dead | | | 6.2 | 1.2 | 6.2 | | | | | 13.6 |
| 1983 | alive | 8.6 | 16.1 | 85.2 | 17.3 | 131.0 | 27.2 | 44.5 | 19.8 | 23.5 | 373.1 |
| | dead | | 1.2 | 6.2 | 6.2 | 12.4 | | 1.2 | | | 27.2 |
| Total | alive | 8.6 | 16.1 | 85.2 | 17.3 | 131.0 | 27.2 | 44.5 | 19.8 | 23.5 | 373.1 |
| | dead | | 1.2 | 43.2 | 9.9 | 38.3 | 2.5 | 1.2 | | | 96.4 |
| | % surv. | 100.0 | 92.9 | 66.3 | 63.6 | 77.4 | 91.7 | 97.3 | 100.0 | | 79.5 |

[1]S-35 refers to the small maples (<10 cm) present in 1935, M-35 refers to those 10 to 19.9 cm in 1935, L-35 refers to those 20 to 29.9 cm in 1935, and S-40 to S-83 refer to the ingrowth at the various inventories.

many new stems in each of those 5-year periods as in the first 5-year period from 1935 and 1940.

During the last 10 years, sugar maple mortality and ingrowth appeared to be in balance. Ingrowth in 1978 and 1983 totaled 43.3 trees, while mortality was 40.8 trees (table 2). The maple mortality appeared to be related to both size and duration of minimal growth. Of the trees dying, 95 percent were smaller than 10 cm when they died. Within the S-35 cohort (trees 4 to 10 cm in dbh in 1935), mortality was 33.7 percent over a 48-year period; while within the S-58 cohort (ingrowth into the 4- to 10-cm dbh class in 1958), mortality was 22.6 percent over a 25-year period.

Total stocking was highest during the last 25 years, increasing from 87.7 percent to 94.6 percent between 1958 and 1983; stocking increased from 76.2 percent to 87.7 percent between 1935 and 1958. Yet the growth of the S-58 cohort in the last 25-year period was similar to that of the S-35 cohort during the first 23-year period (table 3). The tolerance of the maple is likewise indicated by the survival of the portion of the S-35 cohort that remained within the 4- to 10-cm size class, which averaged only 0.079 cm in diameter growth per year (table 3), 0.83 sq cm in basal area growth, and 0.085 m in height growth over the 48-year period.

Table 3.--Dbh growth of maple by groups based on size in 1983.

| Size class | L-35 | M-35 | S-35 | S-58 | L-35 | M-35 | S-35 | S-58 |
|---|---|---|---|---|---|---|---|---|
| | --------(cm)-------- | | | | ------(cm)------- | | | |
| | | DBH 1935 | | | Growth/yr '35 - '83 | | | |
| 4-10 | | | 4.8 | | | | .079 | |
| 10-20 | | 11.4 | 6.2 | | | .082 | .191 | |
| 20-30 | 25.4 | 13.8 | 7.3 | | .095 | .253 | .320 | |
| 30-40 | 22.7 | 18.7 | | | .278 | .281 | | |
| 40-50 | 27.2 | 19.6 | | | .376 | .466 | | |
| | | Dbh 1958 | | | Growth/yr '35 - '58 | | | |
| 4-10 | | | 7.0 | 5.0 | | | .098 | |
| 10-20 | | 13.0 | 10.6 | 6.2 | | .068 | .191 | |
| 20-30 | 26.9 | 19.6 | 14.5 | | .066 | .251 | .311 | |
| 30-40 | 30.1 | 25.9 | | | .321 | .312 | | |
| 40-50 | 35.3 | 29.2 | | | .353 | .420 | | |
| | | Dbh 1983 | | | Growth/yr '58 - '83 | | | |
| 4-10 | | | 8.6 | 7.5 | | | .061 | .099 |
| 10-20 | | 15.4 | 15.4 | 12.2 | | .095 | .192 | .240 |
| 20-30 | 30.0 | 25.9 | 22.7 | | .122 | .256 | .328 | |
| 30-40 | 36.0 | 32.2 | | | .238 | .253 | | |
| 40-50 | 45.2 | 41.9 | | | .396 | .508 | | |

Maple basal area has increased at an average annual rate of 3.05 percent over the entire 48-year period. This rate, which is analogous to an internal rate of return (IRR) on an investment, has ranged from a maximum of 4.08 from 1940 to 1958 to a low of 1.97 from 1958 to 1965 (table 4). It reflects the combined effects of mortality, ingrowth, and survivor growth between each measurement period.

Table 4.--Components of the maple basal area dynamics.

| Year | Live trees | Dead trees | New trees | Survivor Amount | Growth %/yr | IRR |
|---|---|---|---|---|---|---|
| | ----square decimeters----- | | | | --percent-- | |
| 1935 | 101.71 | | | | | |
| 1940 | 123.61 | .35 | 3.93 | 18.32 | 3.61 | 3.98 |
| 1958 | 254.06 | 2.78 | 38.00 | 95.23 | 4.38 | 4.08 |
| 1965 | 291.20 | 5.35 | 5.29 | 37.20 | 2.14 | 1.97 |
| 1973 | 376.26 | 6.24 | 8.06 | 83.24 | 3.65 | 3.25 |
| 1978 | 419.10 | 3.73 | 3.67 | 42.90 | 2.30 | 2.18 |
| 1983 | 481.39 | 24.36 | 3.97 | 82.68 | 4.19 | 2.81 |

The growth of surviving trees was the primary contributor to the basal area increases during all measurement periods (table 4), ranging from 71 percent for the period ending in 1958 to 95 percent for the final period. The annual rate of increase of this component ranged from 2.14 percent to 4.38 percent and was 4.19 percent during the most recent growth period.

Initially, the contribution of ingrowth to the basal area increase was much greater then mortality (table 4). From 1965 to 1978, mortality and ingrowth were essentially in balance. During the final measurement period, the loss in basal area from mortality substantially exceeded ingrowth. However, the growth of the surviving trees was sufficient to maintain a net increase of 2.81 percent in basal area.

Sugar maple most recently composed 7.3 percent of the overstory, which consists of trees 24 to 36 m in height and larger than 35 cm dbh (table 5). The four oak species, which made up 57.3 percent of the overstory, accounted for 83.3 percent of the overstory mortality during the study period.

Table 5.--Species composition of the present overstory and mortality of overstory trees during the study period.

| Species | Number of trees Present 1983 | Mortality |
|---|---|---|
| | -----(per hectare)----- | |
| Sugar maple | 7.4 | 0.0 |
| Black gum | 7.4 | 1.2 |
| Yellow-poplar | 16.1 | 0.0 |
| White oak | 19.8 | 2.5 |
| Scarlet oak | 11.1 | 12.4 |
| Black oak | 22.2 | 6.2 |
| Red oak | 4.9 | 3.7 |
| Shagbark hickory | 2.5 | 0.0 |
| Mockernut hickory | 4.9 | 2.5 |
| Pignut hickory | 3.7 | 1.2 |
| Beech | 1.2 | 0.0 |
| Total | 101.2 | 29.7 |

The present distribution of sugar maple within the stand appears to provide it the opportunity to occupy canopy gaps created by the death of overstory trees. At present, oak, hickory, or yellow-poplar overstory trees are found in 30 percent of the 280 28.9-sq m subareas (i.e. the eight main plots divided into 35 equal-sized

areas). An additional 4 percent of the subareas are occupied by sugar maple overstory trees. Overstory mortality occurred in 4 percent of the subareas between the 1978 and 1983 inventories. The 1983 inventory showed understory sugar maples in 69 percent of the subareas. Thus, sugar maple is sufficiently well distributed throughout the stand to quickly capture most growing space made available by overstory mortality.

## CONCLUSIONS

The sugar maple component of this white oak - yellow-poplar community has increased dramatically during the 48 years of record. Before 1973, the stand was apparently still recovering from past disturbance, but since then has been at or near its average maximum (100 percent) stocking level. The sugar maple component has continued to increase, but to what extent this increase will continue is not certain.

At the past and current rate of increase (3.05 percent and 2.81 percent respectively), sugar maple basal area would equal the total stand basal area of 31.3 sq m per ha between the years 2038 and 2051. This increase in sugar maple would necessarily be accompanied by the elimination of essentially all other species, an unlikely event at best.

Braun (1938) argued that the mixed mesophytic forest is a climax association of the deciduous forest, with much variation in species mixtures from stand to stand. Raup (1956) and others (see White 1979) have discussed the role of natural disturbance factors in old-growth forests. Horn (1976) and others (see Pickett, et. al. 1987) have noted that succession is an idealize representation of what actually occurs in nature. Thus, one could conclude that the mixed mesophytic climax forest varies not only in space but in time as well.

If so, there may be an ebb and flow of individual species over time. The observed sugar maple wave that has been building over the past 48 years may continue unchecked or it may break upon the shores of some natural disturbance.

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LONG-TERM EFFECTS OF A 1932 SURFACE FIRE ON STAND STRUCTURE IN A CONNECTICUT MIXED HARDWOOD FOREST[1]

Jeffrey S. Ward and George R. Stephens[2]

Abstract.--In 1926 woody stems ≥ 1.5 cm dbh were measured and mapped on 9 402x5 m transects (1.82 ha) in a mixed hardwood stand with abundant oak in south-central Connecticut. In 1932 a late summer fire burned approximately a third of the transects. In 1934 a post-fire inventory recorded diameter of survivors and mortality on the burned portion. In 1937 the unburned portion was similarly inventoried. Since 1957 both portions have been inventoried every 10 years. In 1926 the burned and unburned portions had approximately equal density, basal area and mean diameter. During 1926-34 84% of stems died on the burned area, mostly saplings and poles. Basal area decreased 38%. During 1926-37 34% of stems died and basal area increased 17% on the unburned area. During 1934-57 oak (28%) dominated ingrowth on the burned area. During 1937-57 maple (31%) dominated ingrowth on the unburned area. During 1934-57 surviving poles and sawtimber on the burned area grew a third faster than those on the unburned area. In 1987 the burned portion had higher density and basal area, higher absolute and relative amounts of oak and larger mean stem diameter than did the unburned portion.

## INTRODUCTION

Fire has been an integral disturbance factor in eastern deciduous forests, certainly since the arrival of European colonists (Clark 1970) and possibly before (Day 1953, Buell et al 1954, Hicock and Miner 1976). Research has shown that fire can increase the relative importance of oak (Brown 1960, Swan 1970, Carvell and Tryon 1961). The ability of oaks to resprout vigorously and the thick bark on mature stems suggest oaks to be a fire-adapted species group in the Central Hardwood region. Aggressive fire exclusion programs were initiated in the early 1900's (Tillotson 1916, Stickel 1939). Conversion of oak-hickory forests to more mesophytic stands has been attributed in part to reduced wildfire frequency (Little 1973).

The immediate impact of fire is reduction of the density of small stems (Paulsell 1957, Ferguson 1961, Niering et al 1970). Larger stems may be damaged, weakened, or killed depending on the intensity and timing of a fire (Gustafson 1946, Paulsell 1957, Loomis 1973, Wendel and Smith 1986). A dense sprout and seedling layer quickly develops following the fire (Thor and Nichols 1973, Loomis 1977, McGee 1979, Teuke and Van Lear 1982, Wendel and Smith 1986).

The long-term effects of fire on the composition of mixed oak stands is less understood. We contrast 55 years of change in adjacent burned and unburned areas. We examine changes in stand level parameters: density, basal area, size class distribution, and diameter growth rates of poles and sawtimber. Finally, we describe the apparent effect of fire on selected species groups.

## STUDY AREA

The Turkey Hill Tract (46 ha) is in the Cockaponset State Forest in south-central Connecticut. The tract was selected because it was typical of contemporary forests in the state, i.e. an even-aged, second-growth, mixed hardwood forest. In 1987 dominant oaks were approximately 85

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years old with individuals ranging to 110 years (Guinane 1984). Although the history before 1926 is unknown, stone walls indicate at least parts of the area were grazed and multiple-stemmed trees suggest other parts had been cutover in the past.

Most soils found in the tract are fine sandy loams characterized as being extremely stony and somewhat excessively drained to well drained. Small areas of poorly drained and very poorly drained, extremely stony fine sandy loams are found in some drainageways. Each area has been assigned to one of four soil moisture classes: moist (poorly drained), medium (well drained), dry (excessively well drained), and muck (muck and seasonally ponded). The distribution of moisture classes on burned and unburned areas is shown in Table 1. Topography varies from nearly level to locally steep with occasional rock faces. Elevation ranges from 100 to 140 m.a.s.l.

## METHODS

Nine permanent strip transects were established at Turkey Hill in 1926. Transects were 402 m long and 5 m wide. Total transect area inventoried was 1.82 ha. Transects ran north-south at 100 m intervals. Stone monuments were located every 40 m along each transect. Strip maps noting the location, species and diameter of all stems ≥ 1.5 cm dbh (diameter at 1.37 m above ground) were made. Stems were mapped by stretching a 2-chain trailer tape between monuments and measuring the distance from the transect center line with graduated poles (Hicock et al 1931). Since 1926 about 0.22 ha of transect have been disturbed by roads or cutting. These areas have been excluded from the analysis.

In late summer 1932 a fire swept through the north and east portion of the tract. About 0.64 ha of transect burned. The 1934 post-fire inventory recorded all post-1926 mortality, diameter and crown classes of survivors, and any ingrowth on the burned area. The unburned area was reinventoried in 1937. Beginning in 1957 both areas were reinventoried at 10-year intervals. The minimum diameter of mapped stems has been 1.3 cm dbh since 1957. This and subsequent inventories

Table 1.--Distribution of moisture classes (ha) on burned and unburned transects of Turkey Hill Tract, Cookaponset State Forest, Ct.

| Moisture Class | Transect Area Burned | Transect Area Unburned |
|---|---|---|
| | --------(ha)------ | |
| Muck | 0.00 | 0.10 |
| Moist | 0.08 | 0.19 |
| Medium | 0.44 | 0.63 |
| Dry | 0.11 | 0.04 |
| Combined | 0.64 | 0.96 |
| Disturbed | 0.10 | 0.12 |

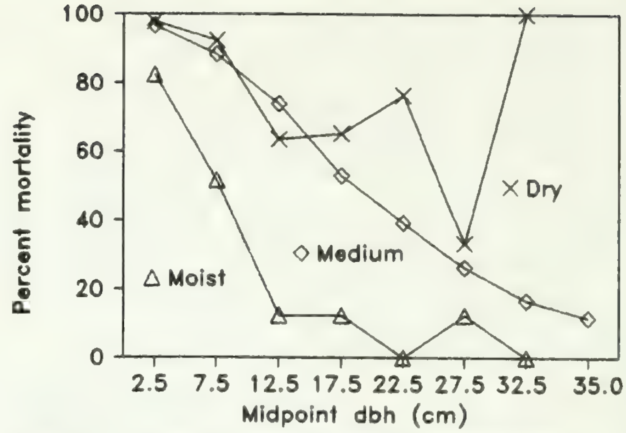


Figure 1.--Mortality (%) 1926-34 by moisture class on the burned portion of Turkey Hill Tract, Cookaponset State Forest, Ct.

recorded stem position, diameter, crown class, ingrowth, mortality, and whether or not the stem was a member of a sprout clump.

Stems were divided into three size classes: saplings (1.3-9.9 cm dbh), poles (10.0-24.9 cm dbh), and sawtimber (≥ 25.0 cm dbh). Six species groups were recognized: maple (Acer rubrum and A. saccharum); birch (Betula alleghaniensis, B. lenta, and B. papyrifera); oak (Quercus alba, Q. coccinea, Q. prinus, Q. rubra, and Q. velutina); hickory (Carya cordiformis, C. glabra, C. ovata, and C. tomentosa); mixed commercial (Fagus grandifolia, Fraxinus americana, F. nigra, Juglans cinerea, Juniperus virginiana, Liriodendron tulipifera, Nyssa sylvatica, Pinus strobus, Populus grandidentata, Prunus serotina, Sassafras albidum, Tilia americana, Tsuga canadensis, and Ulmus americana); and noncommercial (Amelanchier arborea, Betula populifolia, Carpinus caroliniana, Castanea dentata, Cornus florida, Ostrya virginiana).

Average annual mortality rates are presented instead of total inter-inventory mortality losses because of different time intervals between inventories and some large density differences between the burned and unburned areas. Because the 1934 survey recorded mortality without noting its cause, it is impossible to separate pre-fire and immediate post-fire mortality.

## RESULTS

The fire did not burn with equal intensity on all soil moisture classes (Fig. 1). In particular, mortality was lower on moist sites than on medium or dry sites. Mortality on medium and dry sites was similar except for the larger diameter classes. Mortality of stems geater than 15 cm dbh was greater on dry compared to medium sites. To simplify presentation all soil moisture classes are combined in the following sections.

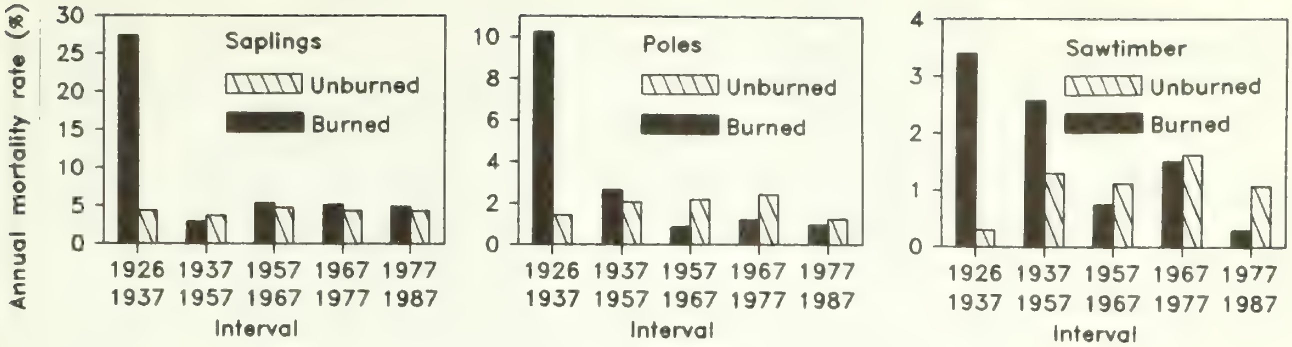


Figure 2.--Annual mortality rates (%) by size class on burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct. First two mortality rates on burned portions are for years 1926-34 and 1934-57.

As might be expected, post-fire mortality was highest for saplings and least for sawtimber (Fig. 2). Since the 1930's mortality rates for saplings and poles on the unburned and burned areas have been similar. After the pulse of fire-related mortality, mortality rates on the burned and unburned areas have been similar. During 1926-34 average annual mortality of sawtimber was 11 times higher on the burned (3.4%/year) compared to the unburned (0.3%/year) area in 1926-37. Some delayed mortality of sawtimber is suspected because average annual mortality during 1934-57 was 2.6% on the burned area compared to 1.3% on the unburned area in 1937-57.

In 1926 density and basal area were similar for the burned and unburned areas: 2476 stems/ha and 17.7 $m^2$/ha, and 2675 stems/ha and 16.4 $m^2$/ha respectively (Fig. 3). Two years after the fire (1934) density was reduced by 84% and basal area by 38% on the burned area. During 1926-37 density on the unburned area fell by only 24% and basal area increased 17%. During 1937-87 density steadily decreased to 1190 stems/ha and basal area has increased to 23.6 $m^2$/ha on the unburned area. During 1934-57 density on the burned area increased to 3976 stems/ha. However, by 1987, density on the burned area, 1400 stems/ha, was close to the density on the unburned area. Since 1934 basal area increased faster on the burned than on the unburned portion; by 1977 basal area on the burned portion was greater than on the unburned portion.

In 1926 the distribution of stems among three size classes was similar on the burned and unburned areas (Table 2). The unburned area had slightly higher densities of saplings and poles than the burned area and a lower sawtimber density. Fire dramatically shifted size class distribution on the burned area. In 1937 on the unburned area there were 10 times as many saplings as on the burned area in 1934 due to high sapling mortality on the burned area. In 1937 the unburned area had nearly 3 times more poles and 25% more sawtimber than the burned area had in 1934.

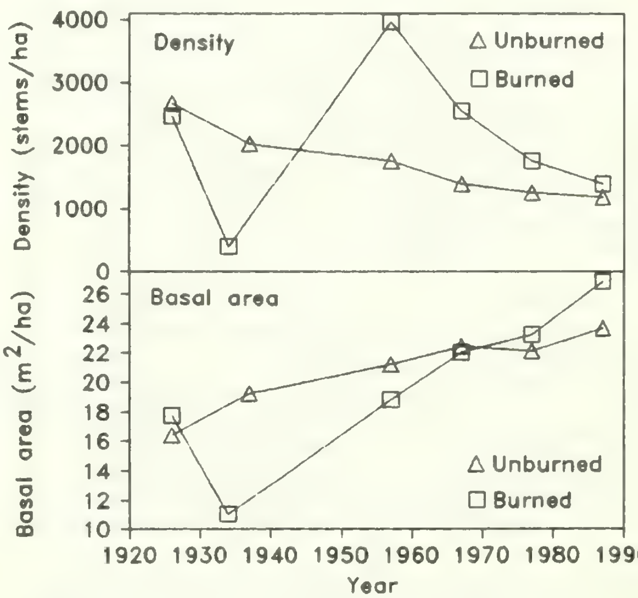


Figure 3.--Density (stems/ha) and basal area ($m^2$/ha) of stems (> 1.3 cm dbh) by year on burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct.

By 1957 density had increased 2500% for saplings and 38% for poles in the burned portion, but decreased 12% for saplings and 24% for poles in the unburned portion. During 1957-87 the density of saplings on the burned and unburned areas converged. In 1987 sapling density on the burned area was nearly equal to 1977 sapling density on the unburned area. Density of sawtimber on both areas has also been converging since the fire. In 1987 sawtimber density on the burned area approached the density of sawtimber on the unburned area. In contrast, densities of poles have diverged since the fire; in 1987 there were 50% more poles on the burned as on the unburned area. The continued increase in the density of poles on the burned area is probably a lag response as

Table 2.--Density of stems (> 1.3 cm dbh) by year and size class on burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct.

| Size class | Portion | Year 1926 | 1937[1] | 1957 | 1967 | 1977 | 1987 |
|---|---|---|---|---|---|---|---|
| -(cm dbh)-- | | (stems/ha) | | | | | |
| 1.3 - 9.9 | Unburned | 2128 | 1405 | 1241 | 918 | 823 | 766 |
| | Burned | 1970 | 140 | 3637 | 2082 | 1269 | 836 |
| 10.0 - 24.9 | Unburned | 481 | 524 | 399 | 330 | 291 | 274 |
| | Burned | 415 | 184 | 253 | 372 | 385 | 426 |
| ≥ 25.0 | Unburned | 66 | 100 | 119 | 147 | 143 | 150 |
| | Burned | 91 | 80 | 86 | 102 | 112 | 138 |

[1] 1934 on burned portion.

individual saplings of the numerous post-fire saplings grew into larger size classes.

Poles and sawtimber stems which survived the fire grew faster than comparable stems on the unburned area (Fig. 4). During 1926-57 stems which were poles in 1926 grew an average of 9.8 cm dbh on the burned area compared to 7.2 cm dbh on the unburned area. Since 1957 poles on both areas had approximately equal rates of diameter increase. During 1926-57 average annual diameter increase of sawtimber which survived the fire was 0.38 cm; from 1957-87 it was 0.30 cm. During 1926-57 average annual diameter increase of sawtimber on the unburned area was only 0.18 cm; from 1957-87 it was 0.19 cm.

Before the fire most species groups had similar densities on the burned and unburned areas (Table 3). Notable exceptions were higher density of hickory on the burned area and higher density of birch on the unburned area. These higher densities may have been related to the higher percentage of moist sites on the unburned relative to the burned area. Oak and noncommercial were the most numerous groups on the tract.

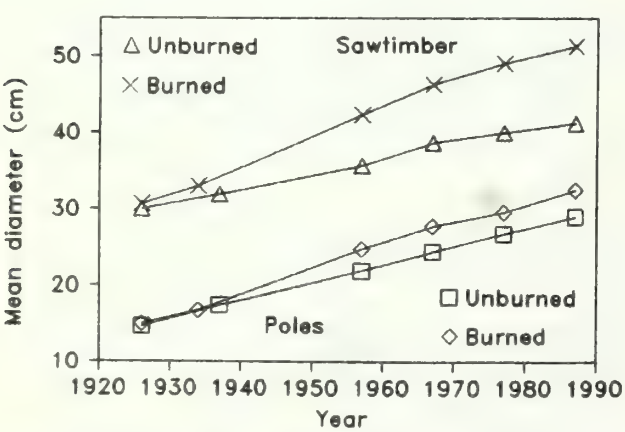


Figure 4.--Average diameter of poles (10.0 - 24.9 cm dbh) and sawtimber (≥ 25.0 cm dbh) which survived the 1932 fire on the burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct.

Table 3.--Density (stems/ha) in 1926, mortality (%) 1926-57 of stems (>1.5 cm dbh) recorded in 1926 and percentage of those stems which had resprouted by 1957 on burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct.

| Species group | Portion | 1926 Density | 1926-57 Mortality | Resprout |
|---|---|---|---|---|
| | | (stems/ha) | --(%)-- | --(%)-- |
| Maple | Unburned | 418 | 48.3 | 8.8 |
| | Burned | 374 | 83.9 | 31.2 |
| Birch | Unburned | 474 | 45.6 | 1.9 |
| | Burned | 308 | 82.7 | 17.9 |
| Oak | Unburned | 527 | 61.3 | 3.3 |
| | Burned | 570 | 87.8 | 40.6 |
| Hickory | Unburned | 90 | 63.8 | 5.6 |
| | Burned | 240 | 96.2 | 30.6 |
| Mixed commercial | Unburned | 350 | 71.4 | 1.2 |
| | Burned | 338 | 96.2 | 12.0 |
| Noncommercial | Unburned | 816 | 78.7 | 2.0 |
| | Burned | 646 | 99.8 | 17.3 |

The immediate impact of the fire was to drastically reduce the densities of all species groups (Fig. 5). The largest reductions were for the hickory and noncommercial species groups which had 94.1% and 99.8% fewer stems in 1934 than 1926. Other species groups had from 66.0% (maple) to 88.5% (mixed commercial) fewer stems. By comparison, density reduction from 1926 through 1937 on the unburned area ranged from 39.3% (noncommercial) to only 5.0% (maple).

There was evidence that some fire-related mortality continued through 1957 in the sawtimber size class (Fig. 2). Therefore, the comparison of species group mortality on the burned and unburned areas included all 1926-57 mortality of stems recorded in 1926. During 1926-57 mortality of all species groups was higher on the burned than on the unburned portion (Table 3). Excluding noncommercial species, mortality on the burned area averaged 41% higher than on the unburned area and ranged from 17% higher for birch to 405% greater for hickory on the burned area compared to the unburned area.

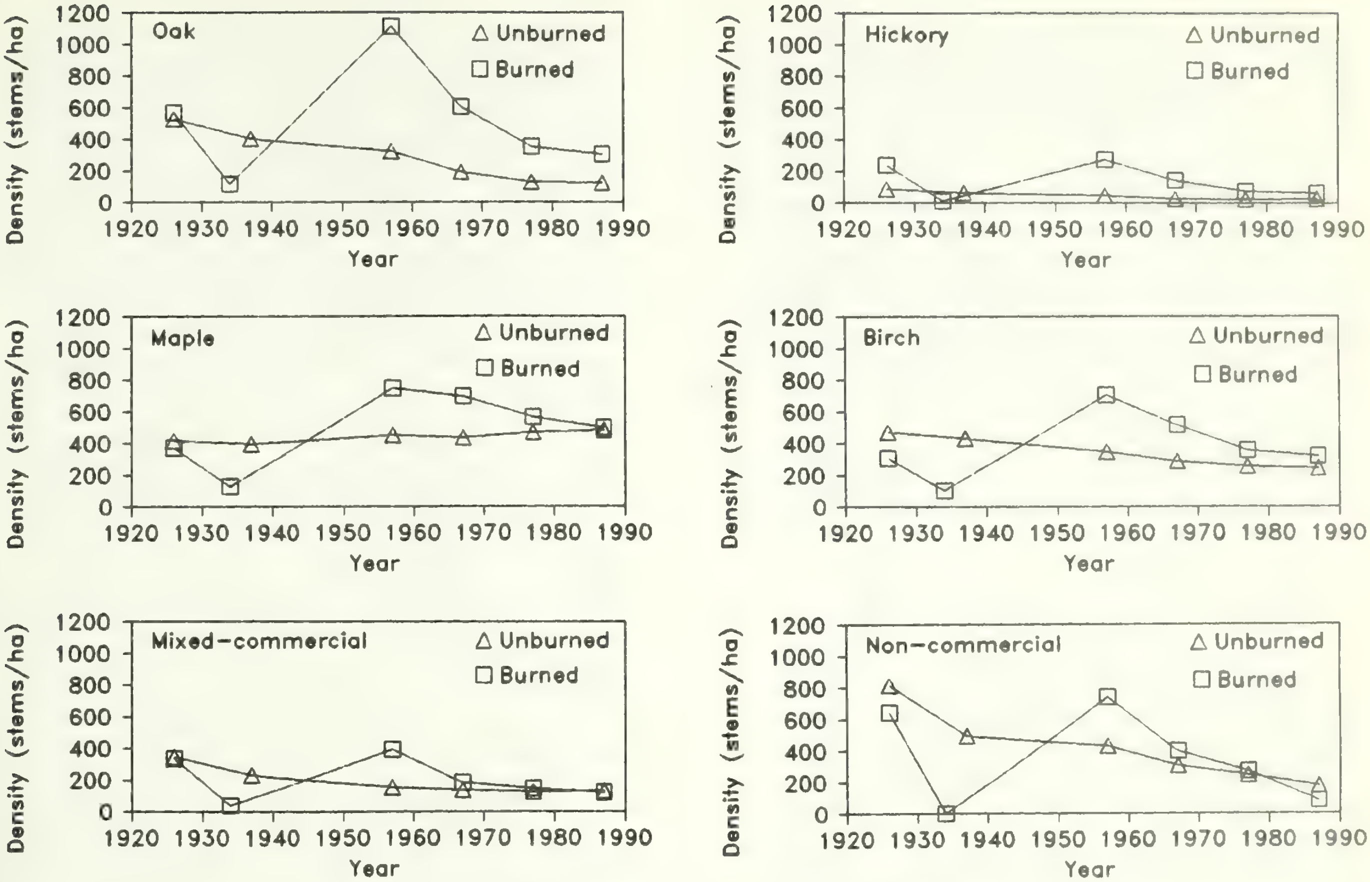


Figure 5.--Density of stems (> 1.3 cm dbh) by year and species group on burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct.

The percentage of stems which resprouted and survived through 1957 was much higher on the burned than on the unburned portion. On the unburned portion resprouting was highest for maple (8.8%) and ranged downward to 1.2% for mixed commercial species. On the burned portion, for a given species group, the proportion of stems which resprouted ranged from 4 times (maple) to 12 times (oak) higher on the burned than on the unburned portion. Over 40% of oak stems which died before 1957 had a measurable resprout by 1957.

Recovery after the fire was rapid and by 1957 all species groups had higher densities than before the fire (Fig. 5). The density of oak, maple, and birch was at least twice pre-fire levels. Over the same time period densities on the unburned area decreased for most species groups. The exception was maple which had a small increase of 34 stems/ha.

The large amount of ingrowth on the burned area resulted from resprouting of pre-1957 mortality and new recruitment (Table 4). Ten times more oak and 20 times more hickory ingrowth was recorded on the burned than on the unburned area.

Table 4.--Density (stems/ha) of 1957 ingrowth by origin and species group on burned and unburned portions of Turkey Hill Tract, Cockaponset State Forest, Ct.

| Species group | Portion | 1937-57 Ingrowth origin[1] Sprout | Non-sprout | Sprout origin |
|---|---|---|---|---|
| | | ----(stems/ha)---- | | -(%)-- |
| Maple | Unburned | 95 | 112 | 46 |
| | Burned | 467 | 218 | 68 |
| Birch | Unburned | 44 | 29 | 60 |
| | Burned | 146 | 501 | 23 |
| Oak | Unburned | 22 | 79 | 22 |
| | Burned | 471 | 571 | 45 |
| Hickory | Unburned | 4 | 9 | 31 |
| | Burned | 105 | 162 | 39 |
| Mixed commercial | Unburned | 17 | 33 | 34 |
| | Burned | 101 | 282 | 26 |
| Noncommercial | Unburned | 108 | 119 | 48 |
| | Burned | 465 | 273 | 63 |

[1] 1934-57 ingrowth on burned portion.

In addition, the burned area had 492 stems/ha more oak ingrowth of non-sprout origin than did

the unburned area. The proportion of all ingrowth that were resprouts of pre-1957 mortality was higher on the burned portion for oak, maple, and noncommercial species. Ingrowth of birch and mixed commercial (32% Liriodendron tulipifera) on the burned portion appeared to be from seed rather than sprouts.

During 1957-87 the trend of decreasing densities of most species groups was observed on both the burned and unburned portions. Again, maple, which increased an additional 28 stems/ha, was the exception. By 1987 the density of three groups (maple, mixed commercial and noncommercial) was the same on the burned and unburned portions. In 1987 on the burned area oak and birch densities were at the 1957 levels of the unburned area and hickory density was at the 1937 level of the unburned area. Thus we find that 55 years after the fire the burned portion had higher relative and absolute levels of oak, birch, and hickory than the unburned portion.

## DISCUSSION

This study indicates that mixed hardwood stands with abundant oak can quickly recover from a major disturbance such as a summer fire and, after a moderate time period (relative to the lifespan of the dominants and codominants), have stand characteristics which approach those of undisturbed areas. Fifty-five years after the fire the burned and unburned portions could not be distinguished by either density or basal area values. In 1987 densities of maple and mixed commercial species groups were similar on the burned and unburned areas. The major long-term effect of the fire was to increase oak and hickory by 240%, increase birch by 30%, and decrease noncommercial species by 50%. Although Turkey Hill has been defoliated at least 3 times since the 1950s and there was a decade of drought from the late 1950s through the early 1960s (Stephens and Waggoner 1980), the effect of these disturbances has been negligible compared to fire-induced structural changes (Figs. 3 and 5).

Perhaps the most important finding from a silvicultural viewpoint is the ingrowth and persistence of oak following the burn. In another study in Connecticut oak seedling density increased after one prescribed burn.[3] Ten years after a fire in Missouri absolute oak density increased although the relative amount of oak decreased (Loomis 1977). In Rhode Island relative oak density was twice as high in burned areas compared to unburned areas (Brown 1960). In West Virginia increased oak regeneration on disturbed areas (including lightly burned) was attributed to increased light (Carvell and Tryon 1961). McGee (1979) reported that relative and absolute oak density in Alabama was higher in a clearcut which had been burned than the control clearcut. A lag time in which top-killed oak were resprouting may explain his short-term observation that the stocking of oaks over 4.5 feet in height was reduced three years after the fire. These findings do not necessarily conflict with the southern practice of prescribed burning to control hardwood understories. Research there has indicated more than one fire is necessary to control hardwoods (Chaiken 1952, Lotti et al 1960). However, oak regeneration is not always enhanced by fire (Teuke and Van Lear 1982, Wendel and Smith 1986). Therefore, the challenge is to find what factors interact with burning to affect oak regeneration density.

Delayed mortality of the sawtimber stems has been reported for New York (Swan 1970) and for Missouri, West Virginia and Pennsylvania (Loomis 1973), and may be related to introduction of disease through fire scars (Hepting 1941). Unfortunately, stem defects were not recorded on Turkey Hill until 1957. Olson (1965) reported that codominants and dominants on the burned area had twice as many stem and crown defects (41%) in 1957 as those on the unburned area (20%). However, the increased percentage of stem defects does not appear to have adversely affected diameter growth.

Stocking, as defined by Gingrich (1971), on the burned area was 100% before the fire and less than 50% after the fire. The increased diameter growth of poles and sawtimber at Turkey Hill may be related to the "heavy thinning" effect of the fire. There have been conflicting reports on the effect of fire on diameter growth of surviving trees. Increased growth on surviving stems was observed following a single fire in Pennsylvania (Perry and Coover 1933). Jemison (1944) reported that growth of black oak and white oak was not affected by wound size, but wounding could decrease growth of scarlet oak in the southern Appalachians. Paulsell (1957) reported that diameter growth of red oak poles was significantly reduced after two fires at five-year intervals in the Missouri Ozarks.

## MANAGEMENT IMPLICATIONS

The long-term consequences of burning of mixed hardwood stands with abundant oak in southern New England appears to be a mixture of favorable and detrimental effects. On the positive side there was a more than two-fold increase in oak and hickory regeneration in the resultant stand after a late summer fire. Trees which survived the fire grew faster than comparable trees on the unburned portion. On the negative side there was a large increase in stem defects and the resulting cull may have more than offset any increased growth. From a timber management viewpoint, it appears that a single late summer fire had a neutral long-term effect on the stand.

[3]Niering, W.A. 1988. Personal communication. Department of Botany, Connecticut College, New London, Ct.

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CANOPY INTERACTIONS WITH ATMOSPHERIC

DEPOSITION AT THREE HARDWOOD FOREST SITES

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and

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Abstract.--Annual ion fluxes in bulk precipitation and throughfall were compared at three deciduous forest sites to examine the role of hydrogen ions and organic compounds in canopy cation exchange. Hydrogen ions explained from 31 to 83% of annual canopy cation losses. Organic compounds played a significant role in canopy cation exchange as either weak acids or neutral salts.

## INTRODUCTION

Loss of base cations from a forest canopy can be due to $H^+$ exchange, washoff of surface deposits, or leaching of neutral salts from tissue (Cronan and Reiners, 1983). Hydrogen ions from strong acids in atmospheric deposition and dissociated weak organic acids from the canopy can exchange for base cations from the canopy. Alternatively, washoff of surface deposited neutral salts or leaching of neutral salts from canopy tissue can represent a major cation loss. Loss of base cations via $H^+$ exchange has been linked to atmospheric deposition of $H^+$ (Price and Watters, 1988), while washoff and leaching of neutral salts can be largely determined by canopy cation availability.

Whether canopy cation losses due to elevated $H^+$ deposition may lead to excessive nutrient loss and soil acidification is unknown. Canopy cation losses are resupplied from the soil by the transpiration stream. If cation supplies from mineralization of organic matter or mineral weathering are insufficient to replenish the losses, soil acidification could result (Ulrich, 1983). Reduced soil and plant pH could increase availability of heavy metals toxic to plants and increase concentrations of $Al^{3+}$ to toxic levels to trout in soil drainage water reaching streams.

The purpose of this paper is to report the results of a year-long study of canopy exchange at three hardwood forest sites with varying fertility on the eastern edge of the Central Hardwood region in an area with some of the highest atmospheric wet deposition of $SO_4^{2-}$ and $H^+$ in North America. The objective of the study was to determine the role of $H^+$ exchange versus washoff and leaching of neutral salts in controlling canopy cation losses, with special attention to the role of organic acids. Overall biogeochemistry for these sites has been described by DeWalle et al. (1988) and DeWalle and Sharpe (1985).

## THEORY

Two methods can be used to estimate the net flux of $H^+$ involved in cation exchange within the canopy: 1) pH measurements and 2) net canopy ion balance. By the first method pH differences between bulk precipitation and throughfall can be used to compute the net $H^+$ flux in the forest canopy ( $F_{H^+}$) as:

$$F_{H^+} = PH^+_{bp} - TH^+_{t} \quad (1)$$

where P is the amount of precipitation in cm $yr^{-1}$, T is the amount of throughfall in cm $yr^{-1}$, and subscripts bp and t refer to concentrations of $H^+$ in meq $L^{-1}$ in bulk precipitation and throughfall,

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respectively. Equation (1) assumes no generation of $H^+$ within the canopy from dissociating organic acids or that organic compounds behave as neutral salts. If organic compounds derived from the canopy occur as organic acids then an additional $H^+$ flux equal to the net flux of organic anions in the canopy (bulk precipitation - throughfall) should be added. Equation 1 then becomes

$$F_{H^+} = PH^+_{bp} - T\,H^+_t + P\,|A^-o_{bp}| - T\,|A^-o_t| \qquad (2)$$

where $Ao^-$ represents the organic anion concentration in meq $L^{-1}$.

The second method of estimating the net flux of $H^+$ in the canopy is the use of an ion balance suggested by Cronan and Reiners (1983). With this method the net flux of cations, excluding $H^+$, in the canopy (bulk precipitation-throughfall) is equal to the total canopy exchange by $H^+$ exchange as well as neutral salt washoff or leaching. The part of the cation flux due to neutral salt washoff and leaching equals the net flux of anions (bulk precipitation - throughfall) in the canopy, since a charge balance must be obtained between cations and anions of neutral salts. The remaining cation flux in the canopy is due to $H^+$ exchange. Thus, the net flux of $H^+$ by this method becomes

$$F_{H^+} = (P\,C^+_{bp} - T\,C^+_t) - (P\,|A^-_{bp}| - T\,|A^-_t|) \qquad (3)$$

or, by rearranging

$$F_{H^+} = (P\,C^+ - |A^-|)_{bp} - T\,(C^+ - |A^-|)_t \qquad (4)$$

where $C^+$ is the base cation sum and $A^-$ is the anion sum both in meq $L^{-1}$. If organic anions are assumed to be derived from neutral salts, the anion sums in Equations 3 and 4 represent total anions and Equation 1 above pertains. If organic compounds exist as weak acids, then the anion sums in Equations 3 and 4 represent only inorganic anions and Equation 2 must be used.

Ideally the ionic concentrations in wet plus dry fallout should be used in the foregoing calculations, rather than bulk precipitation concentrations. However, no reliable method is available to continuously measure dry deposition inputs. Since bulk precipitation flux does include some inputs from larger particulate dry deposition (Lindberg et al., 1986), it is used here as the best available estimate of total atmospheric deposition.

## STUDY SITES

The three deciduous forest sites studied were Peavine Hill on Laurel Mountain in southwest Pennsylvania, Fork Mountain on the Fernow Experimental Forest in north central West Virginia, and Sand Mountain in central Pennsylvania. All sites were gently-sloping, ridge-top sites in the Appalachian Mountains. Forest on Peavine Hill was dominated by saw-timber sized red oak (*Quercus rubra*) and black cherry (*Prunus serotina*) with a fern and *Vaccinium spp.* understory. Fork Mountain forest was also mature, saw-timber sized and primarily included red oak, black cherry, and sugar maple (*Acer saccharum*) with a dense herbaceous understory. Forest at Sand Mountain was composed of large-pole sized chestnut oak (*Quercus prinus*) and white oak (*Quercus alba*) with a mountain-laurel (*Kalmia latifolia*) understory. All sites were underlain by acidic sandstone and shale bedrock. Soils were fine-loamy, mixed, mesic typic Hapludults (Peavine Hill and Stone Mtn.) and loamy-skeletal, mixed, mesic, Typic Dystrochrepts (Fork Mtn.).

## METHODS

### Field

Field methods included biweekly measurement of precipitation and throughfall amounts and collection of bulk precipitation, throughfall and wet fallout samples from November 30, 1983 to November 14, 1984. Precipitation amounts were measured in standard non-recording rain gauges in forest openings near each site. Throughfall amounts were collected beneath the forest canopy with plastic rain gauges randomly located at ten points at Peavine Hill and five locations at each of the remaining two forest sites.

Bulk precipitation and throughfall samples for chemical analysis were collected using composite samples from 17-cm diameter plastic funnels during the growing season. Twelve funnels were employed at Peavine Hill and three funnels were employed at each of the other two sites. During winter, four 36-cm W x 52-cm L x 52 cm-D plastic tubs were used to collect bulk precipitation at Peavine Hill and one tub at each of the remaining two sites.

### Laboratory

Standard methods (EPA, 1983) were employed for water anlyses. Analysis for $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $Mn^{2+}$, $Al^{3+}$, and $Zn^{2+}$ were conducted using atomic absorption spectrophotometry, $NH_4^+$ and $NO_3^-$ analyses were conducted using a Technicon autoanalyzer, $SO_4^{2-}$ was analyzed using both the turbidimetric method and chromatography (Dionex), $Cl^-$ was analyzed using both a chloride titrator and chromatography (Dionex), and pH was measured using an Orion Ionanalyzer. Further details are given in DeWalle, et al. (1988).

Lower canopy tree leaves of species common to all sites were collected in August 1984 for chemical analysis. Three composite samples from leaves of at least ten trees of each species were digested and analyzed using inductively coupled plasma emission spectroscopy for total K, Ca, and Mg content.

## Computations

Annual net flux of $H^+$ using Equations 1 and 2 were computed using annual ion fluxes. Due to the limited number of throughfall collectors used in the study, emphasis was placed on annual ion fluxes. Annual ion fluxes were computed as the product of mean biweekly ion concentration for the one-year period and the measured precipitation or throughfall totals.

Organic anion concentrations were computed as the difference between all measured cations minus all measured anions. As a check on this procedure, mean annual organic anion concentrations for bulk precipitation computed in this manner of 5, 8, and 9 $\mu eq\ L^{-1}$ at Peavine Hill, Fork Mountain and Sand Mountain, respectively, were found to agree well with organic anion concentrations of 6.8 to 14.9 $\mu eq\ L^{-1}$ found in NADP wet deposition samples by Keene and Galloway (1984). Thus, this procedure was deemed reasonable.

## RESULTS AND DISCUSSION

Ion and water fluxes at the three forest sites for the November 1983-84 period are given in Table 1. Bulk precipitation deposition of $H^+$ at Peavine Hill was 63% greater than that at Fork Mountain and 79% greater than that at Sand Mountain primarily due to lower precipitation pH at Peavine Hill. Bulk precipitation of other cation and anion sums were similar among sites. Throughfall flux of $H^+$ was also greater at Peavine Hill, again due to lower pH. Throughfall flux of other cation and anion sums was greater at Fork Mountain., apparently due to greater canopy washoff, leaching and/or $H^+$ exchange. Regardless, canopy water at all sites remained relatively acidic with the maximum pH of 4.40 occurring in Fork Mountain throughfall.

The assumed role of organic compounds had a profound effect on the computed net fluxes of $H^+$ in the canopy (Table 2). If organic compounds act as weak organic acids, then the computed $H^+$ flux in the canopy is greater and equivalent to a larger fraction of total canopy cation loss than for the neutral salt scenario. For example, computed net $H^+$ exchange at Peavine Hill, Fork Mtn. and Sand Mtn. equals 83, 67, and 55% of total canopy cation losses, respectively, with organics acting as a weak acid. These percentages reduce to 64, 36, and 31% at Peavine Hill, Fork Mtn. and Sand Mtn., respectively, if organics act as neutral salts. Cronan and Reiners (1983) found $H^+$ exchange only explained 20% of canopy cation losses in a northern hardwood forest in New Hampshire with little or no organic anion contribution. Their results compare more favorably with the neutral salt scenario in this paper, but the true role of organics can not be determined.

Table 1. Ion and Water Fluxes at Three Deciduous Forest Sites for November 1983 to November 1984

| Flux | Peavine Hill | Fork Mtn. | Sand Mtn. |
|---|---|---|---|
| | ($meq\ m^{-2}\ yr^{-1}$) | | |
| Cations1/ | | | |
| bulk precip. | 130 | 160 | 142 |
| throughfall | 188 | 286 | 191 |
| Anions | | | |
| bulk precip. | | | |
| total2/ | -288 | -257 | -230 |
| organic3/ | -8 | -12 | -11 |
| throughfall | | | |
| total | -309 | -337 | -264 |
| organic | -19 | -50 | -23 |
| $H^+$ | | | |
| bulk precip. | 158 | 97 | 88 |
| (pH) | (4.00) | (4.21) | (4.16) |
| throughfall | 120 | 51 | 74 |
| (pH) | (4.05) | (4.40) | (4.19) |
| | ($cm\ yr^{-1}$) | | |
| Water | | | |
| precipitation | 157 | 156 | 128 |
| throughfall | 134 | 127 | 115 |

1/ $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $NH_4^+$, $Mn^{2+}$, $Al^{3+}$, $Zn^{2+}$
2/ $SO_4^{2-}$, $NO_3^-$, $Cl^-$, organic anions
3/ organic anions estimated as cations including $H^+$ minus anions

Table 2. Canopy Exchange of Hydrogen Ions Using Two Scenarios for Organic Compounds and Two Estimation Methods

| Net Flux1/ | Peavine Hill | Fork Mtn. | Sand Mtn. |
|---|---|---|---|
| | ($meq\ m^{-2}\ yr^{-1}$) | | |
| **Organic Compounds as Neutral Salts** | | | |
| 1. Net $H^+$ flux from ion balance | | | |
| Base cations | -58 | -126 | -49 |
| Neutral salts | -21 | -80 | -34 |
| $H^+$ | 37 | 46 | 15 |
| 2. Net $H^+$ flux from pH measurement | 38 | 46 | 14 |
| **Organic Compounds as Weak Acids** | | | |
| 1. Net $H^+$ flux from ion balance | | | |
| Base cations | -58 | -126 | -49 |
| Neutral salts | -10 | -42 | -22 |
| $H^+$ | 48 | 84 | 27 |
| 2. Net $H^+$ from pH measurement | | | |
| pH measurement | 38 | 46 | 14 |
| Organic acids | 11 | 38 | 12 |
| $H^+$ | 49 | 84 | 26 |

1/Net flux = bulk precipitation - throughfall

Excellent agreement was indicated between methods for computing the $H^+$ flux in the canopy (Table 2). Ion balance estimates based upon Equation 4 agreed within 1 $meq\ m^{-2}\ yr^{-1}$ with estimates based upon pH measurement (Equation 1 or 2).

Results suggest that annual canopy cation losses due to $H^+$ exchange do not vary simply with annual total $H^+$ deposition in bulk precipitation. The greatest $H^+$ exchange in the canopy (46 or 84 $meq\ m^{-2}\ yr^{-1}$) occurred at Fork Mountain where bulk precipitation deposition of $H^+$ (97 $meq\ m^{-2}\ yr^{-1}$) was intermediate in rank among the three sites. Similarly, maximum $H^+$ deposition at Peavine Hill of 158 $meq\ m^{-2}\ yr^{-1}$ was associated with intermediate canopy $H^+$ exchange (38 or 49 $meq\ m^{-2}\ yr^{-1}$). However, minimum $H^+$ deposition did

correspond to minimum $H^+$ canopy exchange at Sand Mountain. Although $H^+$ deposition probably directly influences canopy $H^+$ exchange, other factors, such as cation availability in the canopy, also probably play a role.

Total content of K, Ca, and Mg in tree leaves comprising the canopy at these three sites (Table 3) helps to explain canopy $H^+$ exchange. The generally higher total tree leaf content of K, Ca, and Mg at Fork Mountain may have led to greater availability of these cations for exchange with $H^+$ at this site than the other two sites. Thus $H^+$ exchange for cations in the canopy at Fork Mountain could be more efficient. Indeed, over one-half of $H^+$ in bulk precipitation was exchanged in the canopy at Fork Mountain. In contrast, tree leaves at Peavine Hill had the lowest total K, Ca, and Mg content (Table 3) which contributed to reduced canopy $H^+$ exchange and the fact that only about 23-30% of $H^+$ from bulk precipitation was involved in canopy exchange. At Sand Mountain tree leaf K, Ca, and Mg content was intermediate among the three sites and the fraction of $H^+$ from bulk precipitation involved in canopy exchange (16-31%) was similar to that at Peavine Hill.

Table 3. Mean Chemical Composition of Lower Canopy Tree Leaves at Three Forest Sites in August 1984

| Tree Species | n | Element | Peavine Hill (%) | Fork Mtn. (%) | Sand Mtn. (%) |
|---|---|---|---|---|---|
| Prunus serotina | 3 | K | 1.63 a[1] | 2.47 b | - |
| | | Ca | 0.95 a | 1.26 b | - |
| | | Mg | 0.28 a | 0.68 a | - |
| Quercus prinus | 3 | K | 0.81 a | 1.37 b | 1.05 c |
| | | Ca | 0.49 a | 0.61 b | 0.79 c |
| | | Mg | 0.10 a | 0.20 b | 0.15 c |
| Quercus rubra | 3 | K | 0.84 b | 1.35 b | 0.94 b |
| | | Ca | 0.49 a | 0.79 b | 0.75 c |
| | | Mg | 0.09 a | 0.18 b | 0.15 c |

[1]Means in the same row followed by the same letter are not significantly different between sites at the 95% confidence level

## CONCLUSIONS

Hydrogen ion exchange explained 31 to 83% of total annual canopy cation exchange at three deciduous forest sites. High canopy $H^+$ cation exchange was associated with both high tree leaf total K, Ca, and Mg content and high $H^+$ deposition in bulk precipitation. Assuming organic compounds acted as weak acids also increased the magnitude of the computed $H^+$ exchange. Annual canopy $H^+$ cation exchange was equivalent to 29 to 86% of annual $H^+$ in bulk precipitation for these stands; suggesting that a varying proportion of changes in $H^+$ deposition from the atmosphere would be translated into canopy $H^+$ cation exchange.

The role of organic compounds in canopy cation exchange was important, but ambiguous. As either a weak acid or neutral salt, organic compounds could have contributed from 19 to 30% of annual canopy cation exchange.

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EFFECTS OF FOREST FERTILIZATION ON SELECTED ION

CONCENTRATIONS IN CENTRAL APPALACHIAN STREAMS[1]

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Abstract.--Two small forested watersheds were fertilized in April 1976 with 336 kg/ha N as ammonium nitrate and 224 kg/ha $P_2O_5$ as triple superphosphate in order to determine fertilization effects on streamflow chemistry. Specific conductance and the concentration of nitrate-N and calcium in streamflow increased dramatically after fertilization. After reaching maximum concentrations in October 1976, fertilization effects declined gradually and concentrations were elevated only slightly in July 1979 when intensive sampling ended.

## INTRODUCTION

Modern agriculture requires the use of inorganic fertilizer to maximize crop yields. Since the demand for all forest products is expected to increase during the next few decades (USDA For. Serv. 1982), foresters naturally ask if fertilization will increase the growth rate of trees. Forest fertilization is a relatively new management practice that is limited to areas where potential growth is greatest. Operational forest fertilization began in the Pacific Northwest in 1965 and in the southeastern pine region in 1968 (Moore and Norris 1977). Nitrogen and phosphorus usually are applied because the major coniferous timber types have responded best to these two nutrients (Ballard 1984).

A study of forest fertilization in the central Appalachians began in 1973 on the Fernow Experimental Forest near Parsons, West Virginia. Studies were imposed to determine nitrogen and phosphorus fertilizer effects on: (1) Overstory and understory growth rates; (2) Leaf size and annual leaf litter production; (3) Selected chemical characteristics of streamflow.

Effects of fertilization on growth rates were reported by Lamson (1980) and effects on leaf production were reported by Kochenderfer and Wendel (1982). This paper reports the effects of fertilization on streamflow chemistry and defines the duration of those effects.

## THE STUDY AREA

The study was conducted on the Fernow Experimental Forest in the central Appalachian Mountains near Parsons, West Virginia. Two pairs of small adjacent watersheds were chosen: one pair had a southern exposure and one pair had a northwestern exposure (Fig. 1). Slopes are steep, averaging 30 to 40 percent, and average elevation is 610 m. The soils are Calvin channery silt loams (loamy-skeletal, mixed, mesic, Typic Dystrochrept). These soils are well-drained and strongly acidic, with moderate permeability.

Vegetation is dominated by second growth hardwoods with a scattering of older trees that were left after logging between 1900 and 1910. The most abundant species on the northwest-facing watersheds were American beech (*Fagus grandifolia* Ehrh.), northern red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), sweet birch (*Betula lenta* L.) and red maple (*Acer rubra* L.). On the south watersheds, northern red oak, chestnut oak (*Quercus prinus* L.), red maple, white oak (*Quercus alba* L.), sugar maple, and sweet birch were most abundant. Basal area of all trees larger than 12.5 cm in diameter (measured at approximately 140 cm above groundline) averaged 24.1 $m^2$/ha on the south-facing watersheds and 22.9 $m^2$/ha on the northwest-facing watersheds.

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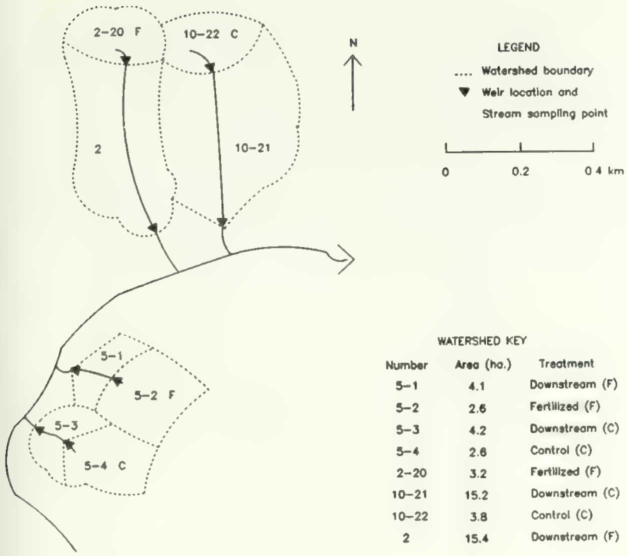


| Number | Area (ha.) | Treatment |
|---|---|---|
| 5-1 | 4.1 | Downstream (F) |
| 5-2 | 2.6 | Fertilized (F) |
| 5-3 | 4.2 | Downstream (C) |
| 5-4 | 2.6 | Control (C) |
| 2-20 | 3.2 | Fertilized (F) |
| 10-21 | 15.2 | Downstream (C) |
| 10-22 | 3.8 | Control (C) |
| 2 | 15.4 | Downstream (F) |

Figure 1.--Location and relative size of watersheds in this study.

Annual precipitation is distributed evenly between the dormant and growing seasons, averaging 148 cm on a nearby control watershed for a 29-year period. Annual runoff from the control watershed for the same period averaged 63.5 cm, 15.2 cm during the growing season and 48.3 cm during the dormant season. Potential evapotranspiration on the Fernow Experimental Forest was estimated at 55.9 cm per year (Patric and Goswami 1968).

## METHODS

Streamflow was measured at the mouth of each watershed with a sharp-crested V-notch weir and FW-1 water-level recorder. Monthly streamflow volumes were summarized by computer at the Coweeta Hydrologic Laboratory at Otto, North Carolina.

Each stream was grab-sampled with plastic bottles just upstream from the weir beginning in August 1972. Samples usually were taken every 7 days; however, some sampling periods were slightly longer or shorter depending upon accessibility, weather, etc. No sampling periods were shorter than 5 days or longer than 9 days, and all streams were sampled on the same day. To assess the downstream dilution effect of fertilization on stream chemistry, samples also were collected downstream from both subwatershed pairs (Fig. 1). The drainage area of the downstream sampling point below the south fertilized watershed is about 15.4 ha and the distance is about 450 m. Comparable area and distance downstream from the northwest-fertilized watershed is 4.1 ha and 150 m.

The watershed pairs were calibrated for selected stream chemical constituents over a 33-month period: on April 28 and 29, 1976, one of the northwest-facing watersheds (northwest-fertilized) and one of the south-facing watersheds (south-fertilized) were treated with 336 kg/ha N as ammonium nitrate and 224 kg/ha $P_2O_5$ as triple superphosphate. The choice of these fertilizers and application rates was based on research by Auchmoody and Filip (1973). They measured a significant growth increase by northern red oak and yellow-poplar after a similar application of fertilizer to a mixed hardwood stand on the Fernow Experimental Forest. A grid of 30.5 x 30.5-m squares was established on the fertilized watersheds, and a premeasured amount of fertilizer was hand-broadcast with cyclone seeders onto each of these squares. This procedure provided an even distribution of fertilizer. Care was taken to avoid applying fertilizer directly into the streams. The two untreated watersheds (northwest control and south control) were maintained in their natural condition.

Routine grab sampling continued on each of the 4 subwatersheds and 4 downstream locations through April 1979. Watersheds 5-2 and 5-4 were sampled biweekly in 1986 and 1987 to determine whether fertilization effects had disappeared.

The samples were analyzed at the Northeastern Forest Experiment Station's Timber and Watershed Laboratory in Parsons. The 1973-79 calcium, sodium, magnesium, and potassium determinations were made with a 390-B Perkin Elmer atomic absorption spectrophotometer. Nitrate and phosphate were determined colorimetrically with a Bausch and Lomb Model 10 spectrophotometer and Nitro Ver IV and Phos Ver III powder pillow chemicals, respectively (Hach Chemical Co. 1975). Sample pH and conductivity were determined with a Model 10 Corning meter and Industrial Instruments Solu-Bridge meter, respectively. Samples collected in 1986 and 1987 were analyzed as follows: Anions: Dionex Model 10 ion chromatograph; Cations: Model 503 Perkin Elmer atomic absorption spectrophotometer; pH: Altex digital pH meter; conductivity: Markson Model 1096 digital meter. Comparison tests between each old and new instrument indicated good agreement between each pair.

For this paper, stream-chemistry data were analyzed by plotting average monthly concentrations of each constituent over time. No statistical tests for fertilization effects were performed. Instead, graphs are used to illustrate changes in stream chemistry caused by fertilization.

## RESULTS AND DISCUSSION

A graph for each constituent that was affected by the fertilizer is presented. Where both fertilized watersheds responded about equally, results from only one fertilized watershed and its control are presented. Downstream dilution effects are illustrated with graphs that show concurrent concentration at the outlet of the fertilized watershed and the sampling site downstream.

Specific Conductance. Before fertilization, specific conductance of streamflow from both watershed pairs was similar, averaging about 28 µS/cm. Monthly streamflow was low during the first 5 months after fertilization (Fig. 2). In October 1976, streamflow increased in response to abundant rainfall, and specific conductance of streamflow from both fertilized watersheds increased to 140 µS/cm (Fig. 3). Average monthly conductance fluctuated in response to monthly streamflow during the 1976-77 dormant season. Conductance decreased gradually after November 1977; when the study ended in 1979, conductance of the fertilized streams averaged about 40 µS/cm, about 10 µS/cm greater than that of the controls. In 1986 and 1987, streamflow conductance from both fertilized and control watersheds averaged about 32 µS/cm, indicating that the effects of fertilization on stream chemistry had essentially disappeared.

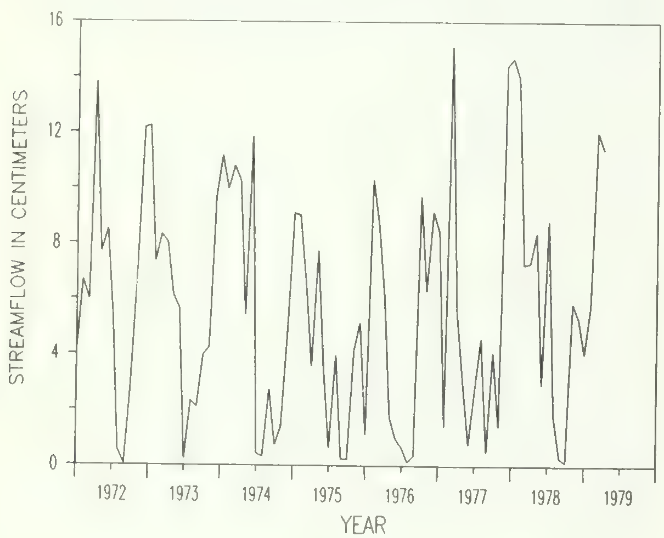


Figure 2.--Measured monthly streamflow from control watershed on Fernow Experimental Forest from 1973-79.

Although specific conductance is a sensitive indicator of total dissolved solids, it gives no indication of the concentration of individual ions. Thus, results for specific conductance indicate major changes in ionic strength of stream water after fertilization. On the basis of previous research (Aubertin et al. 1973), we expected major changes in streamflow concentrations of nitrate-nitrogen and calcium after fertilization.

Nitrate-Nitrogen. Nitrate-N responded in a similar fashion to specific conductance (Fig. 4). Concentrations increased from both fertilized watersheds 5 months after fertilization. Maximum monthly concentrations were 8.5 and 7.3 mg/l on the northwest-facing and south-facing fertilized watersheds, respectively.

Maximum concentration of individual stream samples from the south-facing fertilized watershed was 11 mg/l on September 27, 1976, and the maximum from the northwest-facing fertilized watershed was 13 mg/l on October 4, 1976. Nitrate-N concentrations increased and decreased in response to increases and decreases in flow rate from October 1976 to April 1978. After April 1978, concentrations decreased gradually and were only about 1.0 mg/l when the intensive sampling ended in 1979. In 1986 and 1987, nitrate-N was slightly higher in the fertilized (0.9 mg/l) than in the control (0.5 mg/l) streams; however, these differences are small when compared to the magnitude of the nitrate-N values immediately following fertilizatio

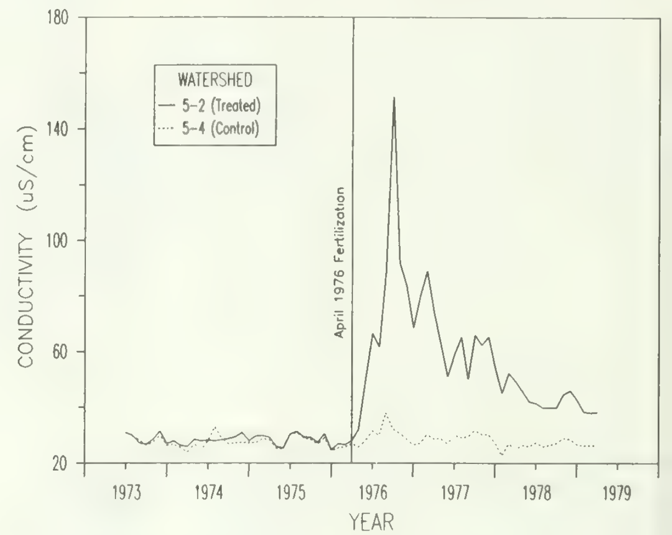


Figure 3.--Average monthly conductivity (µS/cm) of streamflow from Watersheds 5-2 and 5-4. Specific conductance of Watersheds 2-20 and 10-22 responded similarly.

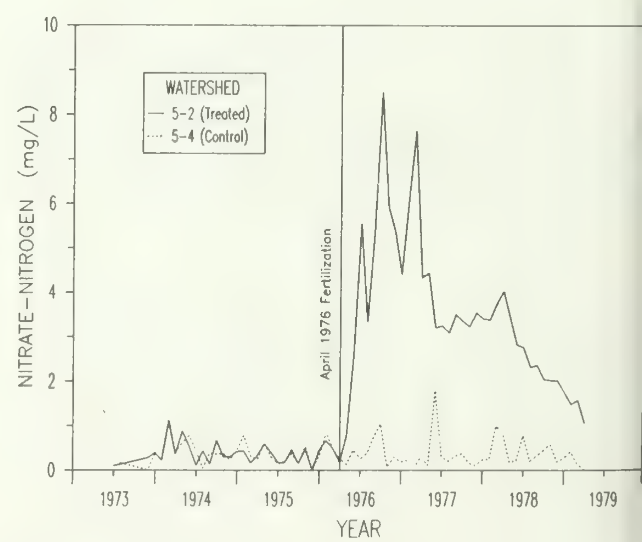


Figure 4.--Average monthly streamflow concentrations of nitrate-nitrogen (mg/l) from Watersheds 5-2 and 5-4. Nitrate-N concentrations of streamflow from Watersheds 2-20 and 10-22 responded similarly.

Calcium. Calcium concentrations increased sharply about 5 months after fertilization (Fig. 5). After the peak in October 1976, concentrations decreased rapidly until the growing season of 1977 began, then decreased gradually for the remainder of the study. When the study ended in 1979, calcium levels were still about 1 mg/l greater than before fertilization. In 1986 and 1987, average concentration of calcium in streamflow from fertilized and control watersheds was the same (1.9 mg/l).

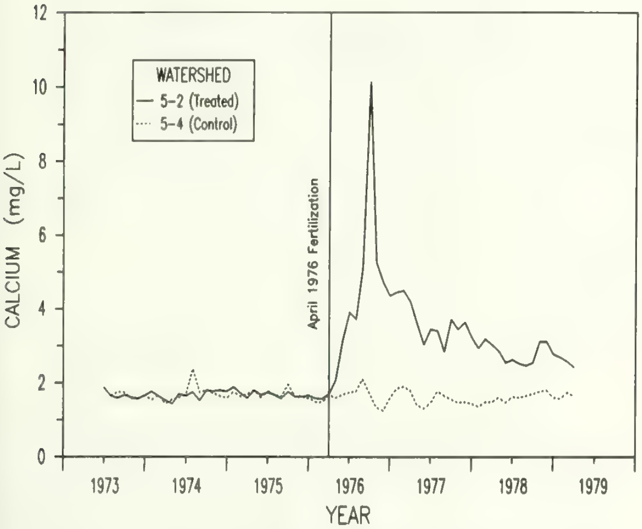


Figure 5.--Average monthly streamflow concentrations of calcium (mg/l) from Watersheds 5-2 and 5-4. Calcium concentrations of streamflow from Watersheds 2-20 and 10-22 responded similarly.

Phosphate-phosphorus. Since 224 kg/ha of $P_2O_5$ were applied to the watersheds, streamflow was monitored for changes in concentrations of $PO_4$-P. Before fertilization, concentrations of all sampled streams averaged about 0.05 mg/l $PO_4$-P. There were no obvious changes in concentration after fertilization (Fig. 6). This result was not surprising since other studies (Black 1968; Tiedemann et al. 1978) reported a low degree of mobility for $PO_4$-P. In acidic forest soils, phosphorus leaching is minimal, even after fertilization, because most of the phosphorus is quickly immobilized via solubility reduction reactions involving aluminum and iron (Black 1968; Khanna and Ulrich 1984). Some added phosphorus also may have been assimilated immediately or over time by microorganisms or vegetation.

Other Chemical Constituents. Average annual pH of streamflow from the fertilized watersheds decreased from 5.3 before fertilization to 5.05 during the first year after fertilization. During the last year of intensive sampling, pH averaged 5.2. The concentrations of potassium, sodium, and magnesium increased slightly after fertilization. However, because the magnitudes were small, no figures are presented here.

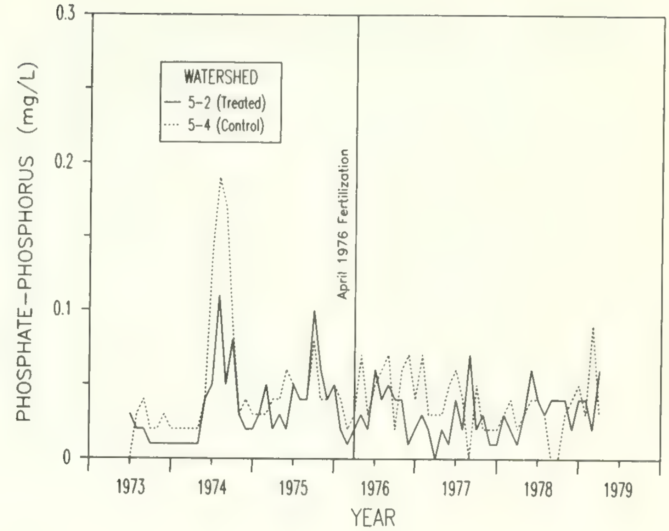


Figure 6.--Average monthly streamflow concentrations of $PO_4$-P (mg/l) from Watersheds 5-2 and 5-4. There was no obvious effect of fertilization.

The fertilizers caused indirect effects on ionic outputs. Calcium concentrations increased within a few months after fertilization, and levels remained elevated for more than 3 years. Changes in other constituents including pH, magnesium, and sodium were small. Briefly, when excess ammonium nitrate is applied to an ecosystem, the ammonium is oxidized by microbes to produce nitrate (Carlyle 1986), which is more mobile than ammonium. Also, production of hydrogen ions during nitrification can lead to increased cation loss and can increase the concentration of base cations in solution as a result of cation exchange (Carlyle 1986). These anion/cation processes probably were responsible for the observed increases in nitrate, calcium, and potassium concentration, and the slight decrease in streamflow pH levels.

Although concentrations of some ions increased following fertilization, water quality remained within drinking water standards (Public Health Serv. 1962) except for 3 weeks in September and October 1976 when $NO_3$-N concentrations exceeded the 10-mg/l standard. Even these excessive concentrations decreased to acceptable levels as the water flowed several hundred meters downstream where it became diluted with water from unfertilized areas. Thus, forest fertilization in the hardwood type of the central Appalachians seems an acceptable practice with regard to water quality.

Downstream Dilution. Downstream effects are important considerations of forest management activity on a headwater stream. Since nitrate is an important ion from the standpoint of municipal water supplies and human and domestic animal consumption, only the downstream effects on $NO_3$-N are presented (Fig. 7). On the northwest-facing watersheds, nitrate-N concentrations were diluted

downstream as water from unfertilized areas mixed with water from the fertilized watershed. As expected, downstream dilution was greater on the south watershed because the unfertilized drainage area and resulting streamflow volume were approximately 3 times greater than for the northwest-facing watersheds (Fig. 1).

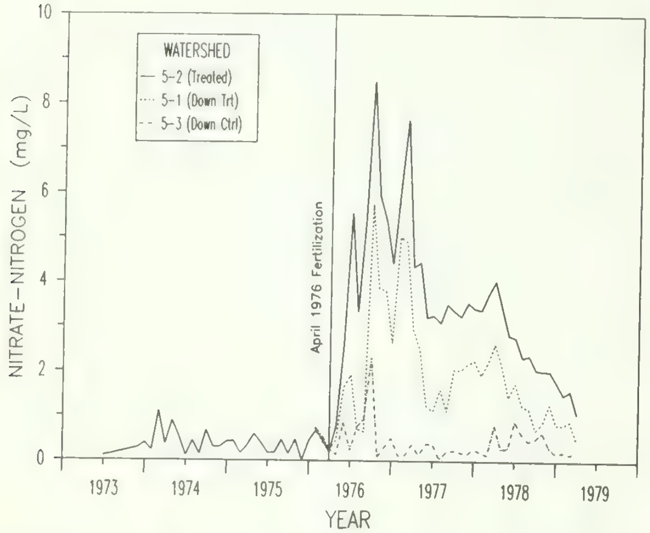


Figure 7.--Average monthly streamflow concentrations of nitrate-N (mg/l) from fertilized Watershed 5-2 (top graph), Watershed 5-1 located about 100 meters downstream of fertilized area (middle graph), and Watershed 5-3 control (bottom graph).

## CONCLUSION

Stream-water chemistry was affected more by ammonium nitrate than by the triple superphosphate fertilizer. Nitrate-nitrogen concentrations increased sharply following fertilization, and these elevated levels remained for more than 3 years on both the northwest-facing and south-facing slopes. By contrast, phosphate output levels showed no obvious changes as a result of fertilization.

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# HYDROLOGIC IMPACTS OF MECHANIZED SITE PREPARATION IN THE CENTRAL APPALACHIANS[1]

J. N. Kochenderfer[2]
J. D. Helvey

Abstract.--The effects of mechanized site preparation on sediment yield, streamflow chemistry, water temperature, and water yield were evaluated for a 4-year period on a 28.6 acre watershed. Annual sediment yields were slightly higher after site preparation, but not enough to be statistically significant (0.05 level). Growing season streamflow increased by 3.9, 2.8, and 1.5 inches during the first, second, and third growing seasons after the treatments, respectively. Nitrate concentrations of streamflow increased slightly, but stream temperature did not change.

## INTRODUCTION

While mechanical site preparation is common in the South prior to planting pine species, similar methods are relatively new in the central Appalachians. Foresters are concerned that this method will increase erosion and cause other environmental problems on the steep slopes of the central Appalachians, where annual precipitation averages 50 to 60 inches. During mechanical site preparation, the surface litter layer is commonly removed or displaced and surface soil may be pushed into windrows. Douglass and Goodwin (1980) believed it is one of the most severe practices applied to forest land. Mechanical site preparation commonly exposes soil on 50 percent or more of treated areas. Thus, disturbance is much greater than the 10 percent required for roads and landings where wheeled skidders are used for timber harvests in the central Appalachians (Kochenderfer 1977). The large percentage of soil exposure associated with mechanical site preparation, when combined with soil compaction, can lead to sediment-producing overland flows and large increases in stormflow volumes (Ursic and Douglass 1978).

The objective of this study was to evaluate the hydrologic responses of mechanical site preparation on an Appalachian watershed.

## THE STUDY AREA

Two watersheds were used for the study, both in the unglaciated Allegheny Plateau region of north-central West Virginia, within a 10-mile radius of Parsons. One of the watersheds was treated (Clover) and the other retained as a control (Fernow). Precipitation is distributed evenly between dormant and growing seasons on both watersheds; the annual average is 58 inches at Fernow, 61 inches at Clover. Annual runoff from the Fernow watershed for the same period of record averaged 28 inches, 8 inches during the growing season and 20 inches during the dormant season.

The Clover watershed (28.6 acres) has a southern aspect and an average slope of 25 percent. The predominant soil is Calvin channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrept) underlain with fractured sandstone and shale of the Hampshire formation (Losche and Beverage 1967). It is rated as having a moderate erosion hazard (Losche and Beverage 1967). The Clover watershed was farmed for many years before 1930 (Lima and Patric 1978). After farming ended, natural revegetation by poor-quality hardwoods proceeded until this study began in 1983. Past erosion is visible on the upper slopes. Colluvial soil deposits along the stream apparently were eroded from upper slopes during the many years of cultivation. Even before site preparation, the silted stream channel was unstable, with a noticeable lack of rock. Stream banks were raw and eroding in several places.

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[1]Paper presented at the 7th Central Hardwood Forest Conference, Southern Illinois University, Carbondale, Illinois, March 5-8, 1989.

[2]The authors are research foresters with the Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Timber and Watershed Laboratory, Parsons, West Virginia 26287.

The Fernow watershed (96 acres) which faces southeast has not been disturbed since the original timber was removed between 1905 and 1910, except for a road constructed along its upper boundary in the 1930's. Common tree species are yellow-poplar (Liriodendron tulipifera L.), sugar maple (Acer saccharum Marsh.), and northern red oak (Quercus rubra L.). The predominant soil also is Calvin channery silt loam. The stream channel is well armored with sandstone rock and stream banks are protected with vegetation.

## METHODS

### Streamflow and Sediment Loss

Streamflow was measured with 120$^{\circ}$ V-notch weirs. Each weir was equipped with an FW-1 water-level recorder and a Coshocton wheel sediment sampler which diverted 0.5 percent of the total flow into a 600-gallon storage tank. Two samples from each tank were taken weekly during base flow and before the tanks overflowed during storms. Tank contents were agitated vigorously while two 800-ml samples were collected from a spigot on the bottom of the storage tanks. These samples were vacuum-filtered in the laboratory to determine sediment concentrations (mg/l).

Yield of suspended sediment was computed as measured streamflow for the sampling period multiplied by average sediment concentration of the two tank samples. Annual suspended sediment yield is the sum of these computed periodic yields.

Bedload was trapped at each watershed with a box where stream velocity decreased prior to spilling onto the Coshocton wheel. The bedload trapped by each box was measured periodically to determine its cubic-foot volume. Subsamples were collected and ovendried to determine average bulk density. Sediment volume times average dry bulk density gave sediment weight in each box. Suspended sediment plus bedload provided annual sediment export from each watershed.

## STREAMFLOW CHEMISTRY

Streamflow from both watersheds was grab-sampled at weekly or biweekly intervals starting in 1980. These samples were analyzed for pH, specific conductance, and concentrations of $NO_3$-N, $SO_4$, Ca, Mg, K, Na, and $NH_4$-N. Tests for site-preparation effects on streamflow chemistry were made in two ways. First, a plotting of annual average concentration for each chemical constituent indicated whether major changes were associated with site preparation. Second, streamflow losses of selected ions ($NO_3$-N, $NH_4$-N, $SO_4$, and Ca) were calculated by multiplying average weighted quarterly concentration of each ion by the measured quarterly streamflow. Although this is not the most rigorous method for computing losses, Dann et al. (1986) concluded that it provides reasonable results. Simple linear regressions of quarterly losses from the control (independent variable) and treated watershed (dependent variable) were tested for common slopes and intercepts for before-treatment and after-treatment periods.

## STREAM TEMPERATURE

A maximum and minimum thermometer was placed just above the weir in each stream. Weekly maximum and minimum temperatures were recorded for both watersheds during several years prior to site preparation. Records for the first 2 years after site preparation were tested by regression analyses to determine whether weekly stream maximum temperature during the growing season (May-Oct) and minimum temperature during the dormant season (Nov-Apr) changed after site preparation.

## WATER YIELD

The paired watershed technique was used to determine site preparation effects on growing- and dormant-season water yield. This procedure has been described many times in the literature. A unique feature of this study is the distance (about 12 miles) between the control and treated watersheds. Storms, especially during summer months, do not always occur equally on both watersheds. To compensate for differences in rainfall amounts between the two areas, a precipitation difference term is included in the following equations for predicting growing- and dormant-season streamflow:

Growing Season: (1)

$$Q_9 = 1.50 + 0.98\, Q_4 + 0.67\, (P_9 - P_4) \qquad R^2 = 0.975$$

Dormant Season: (2)

$$Q_9 = 4.48 + 0.90\, Q_4 + 0.12\, (P_9 - P_4) \qquad R^2 = 0.87$$

In these equations, $Q_9$ is predicted streamflow (inches) from the Clover watershed; $Q_4$ is measured streamflow (inches) from the Fernow Watershed; and $P_9$ and $P_4$ is average seasonal precipitation (inches) on the Clover and Fernow watersheds, respectively.

### Vegetation Survey (pretreatment)

The overstory on the Clover watershed was tallied on 41 systematically located 0.01 acre plots in October 1983. All trees larger than 1 inch d.b.h. were included. Basal area was 56.5 $ft^2$/acre and volume was 807 $ft^3$/acre. Average diameter of measured stems was 4.7 inches.

Pretreatment ground cover was estimated on 41 milacre plots taken at the same points. About

39 percent of the pretreatment surface area was classed as "open"--not shaded by other vegetation (Table 1). Approximately 3 acres were still in old fields covered with a variety of grasses, e.g., Panicum spp. L. and tall redtop (Triodia flora L.); widely-scattered mountain laurel (Kalmia latifolia L.); clumps of blueberries (Vaccinium spp. L.); and small hardwoods. The remaining acreage was forested, common species being red maple (Acer rubrum L.), sassafras (Sassafras albidum (Nutt.) Nees), flowering dogwood (Cornus florida L.), blackgum (Nyssa sylvatica Marsh.), sourwood (Oxydendron arboreum (L.) DC), and hickory (Carya spp. Nutt.).

Table 1. Ground cover and soil disturbance on the Clover watershed.

| Item | Measurement date | | | | |
|---|---|---|---|---|---|
| | 9/83[a] | 5/84 | 9/84 | 9/85 | 10/86 |
| | Percent | | | | |
| Woody | 22 | 2 | 28 | 30 | 22 |
| Semi-woody | 15 | - | 20 | 24 | 26 |
| Grasses | 13 | 8 | 17 | 30 | 42 |
| Herbaceous | 11 | 4 | 6 | 8 | 4 |
| Open | 39 | 82 | 27 | 7 | 5 |
| Debris | - | 4 | 2 | 1 | 1 |
| Total | 100 | 100 | 100 | 100 | 100 |
| Bare soil | - | 45 | 15 | 7 | 5 |
| Mixed litter and soil | - | 38 | - | - | - |
| Undisturbed litter | - | 17 | - | - | - |

[a]Pretreatment year.

## Treatments

A "minimum-standard" access road as described by Kochenderfer et al. (1984) was constructed into the Clover watershed in June 1983. About 30 Mbf of widely scattered sawtimber trees were removed in August. The area was opened to the public for free firewood in September. Additional skidroads, suitable for dry weather use by pick-up trucks, were constructed in October. Most trees larger than 6 inches d.b.h. were removed.

## Site Preparation

We attempted to use the same site-preparation procedures observed on private land. It was done by the same contractor who does much of the work on private lands in this area. The D7F tractor was equipped with a root rake (Fig. 1). The brush was windrowed, mostly along the contour and around the perimeter of the treated area (Fig. 2). Root raking was done carefully to minimize soil disturbance and windrows were not burned. Stumps were cut low so they could be left intact, even when it meant leaving scattered pieces of slash around them. Roads were used for windrow locations when possible. The site treatment was completed in three days--November 30-December 2, 1983.

Figure 1.--Root raking on Clover watershed November 1983.

Figure 2.--Freshly root-raked watershed showing brush windrowed along contour.

An aerial view of the Clover watershed is shown in Figure 3. An undisturbed 3.5-acre buffer zone was left untreated along the stream. A steep (30+ percent) 3-acre area in the northwest corner of the watershed was not site prepared. Instead, trees on this area that were larger than 1 inch in diameter were injected with an herbicide during the summer of 1984. Except for the untreated

3.5-acre buffer strip, the watershed (25.1 acres) was planted with Japanese larch (Larix leptolepis Sieb. and Zucc.) in the spring of 1984.

Figure 3.--Aerial view of Clover watershed in 1984 shows 3.5-acre buffer zone. The 3-acre area not site prepared is in upper left corner.

### Post-Treatment Vegetation Measurements

To determine surface disturbance and ground cover, 93 permanent sampling points were systematically distributed on a 100 x 100-foot grid on the Clover watershed. The percentage of disturbance created by root raking and percent groundcover were subjective estimates made on circular milacre plots at each sampling point. Three classes were used to estimate surface disturbance when the first observations were made in May 1984: (1) undisturbed, litter intact, (2) mixture of litter and soil, (3) bare mineral soil exposed. Later it was not possible to distinguish the less disturbed classes so only bare soil was recorded. The percentage of ground cover also was estimated to the nearest 5 percent on the same milacre plots. Species that covered at least 5 percent of plot area were recorded. Ground cover was separated into four vegetation classes: (1) woody, (2) semi-woody (blackberry, greenbrier, grape), (3) grasses, and (4) herbaceous (herbs and ferns).

## RESULTS AND DISCUSSION

### Ground Cover

Except for some grasses (mostly Panicum spp. L. and redtop) and scattered patches of clubmoss (Lycopodium spp. L.), root raking removed a large proportion of vegetation from the area. Natural revegetation was rapid (Fig. 4). After root raking, the amount of ground cover classed as open (no live vegetative cover) increased by about 43 percent beyond pretreatment conditions (Table 1). Then the open class decreased by about 55 percent over the first growing season; by the end of the second growing season, the area classed as open had decreased to 7 percent, much less than was measured before treatment.

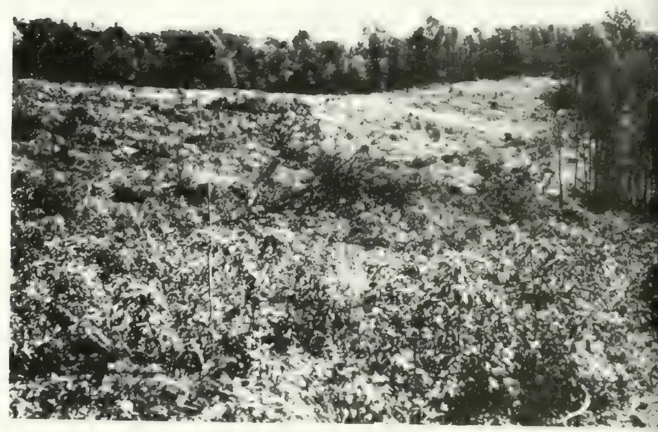

Figure 4.--View of Clover watershed in September 1985 shows dense ground cover developed in two growing seasons.

At the end of the 1986 growing season, grasses accounted for 42 percent of the ground cover. The next largest group of plants (semi-woody) was composed about equally of blackberry (Rubus spp. L.) and greenbrier (Smilax spp. L.). The most common woody species was Sassafras. The decrease of woody component in 1986 probably can be attributed to a herbicide applied to stump sprouts growing near larch trees during the summer of 1986.

Natural succession greatly reduced exposure of bare soil (Table 1). The longest lasting soil exposure was in parts of the road system not covered with windrows and in depressions left when occasional large stumps were pushed out.

## SEDIMENT LOSSES

The Fernow watershed consistently yielded much less sediment (Table 2). The inherent stability of its stream channel and minimal disturbance for over 80 years probably account for consistently lower yields. The Clover watershed, its silted stream channel attributed to its past farming history, yielded more sediment throughout the measurement period.

Table 2. Annual sediment yield from the study watersheds.

| Watershed | Pretreatment 1980 | 1981 | 1982 | 1983 | Post-treatment 1984 | 1985 | 1986 | 1987 | Mean |
|---|---|---|---|---|---|---|---|---|---|
| | lb/acre | | | | | | | | |
| Clover | 235 | 234 | 291 | - | 318 | 363 | 521 | 173 | 305 |
| Fernow | 28 | 36 | 34 | 30 | 24 | 35 | 193 | 23 | 50 |

Measured sediment losses from the Fernow watershed always was less than the 300 lb/acre/yr that Douglass (1975) considered as normal erosion from fully stocked forests. Source areas of eroded soil are primarily stream channels and banks. Sediment losses from the Clover watershed were an average of 6 times greater than losses from the Fernow watershed, averaging 305 lb/acre/yr over a 7-year period. Sediment yields from the Clover watershed are only slightly higher than those summarized by Patric et al. (1984) for undisturbed forest plots and small watersheds in the Eastern United States.

The average annual sediment concentration for the 7 years of record was only .0009 ton/acre-inch (8 ppm) for the Fernow watershed and .005 ton/acre-inch (40 ppm) on the Clover watershed. Both concentrations are lower than the representative base rate suggested for undisturbed forest in the Piedmont and Coastal Plain, but they are within the range for undisturbed forests in the Ozarks and Quachita Mountains (Ursic 1986).

The large sediment losses from both watersheds in 1986 was caused by a 5-inch storm with an estimated recurrence interval of 100+ years. This single storm, which set flow records on all Fernow experimental watersheds, caused widespread flooding along local rivers and produced 77 percent and 69 percent of the annual sediment losses on the Fernow and Clover watersheds during 1986, respectively. The importance of occasional large storms in exporting sediment has been noted by other investigators. A single large storm accounted for 90 percent of annual sediment loss on a control watershed in northern Mississippi (Beasley 1979). Kochenderfer and Wendel (1980) found that 90 percent of the annual sediment loss from a 140-acre watershed in central West Virginia was exported in only 5 percent of the time.

Although average annual sediment yields from the treated watershed were greater after site preparation (Table 2) because of uneven storm distribution between the two watersheds, the increase was not significant at the 95-percent probability level. We believe that the following factors were responsible for preventing larger sediment losses. First, roads were built on the contour, then most of the slash was windrowed in them or on the contour. No sediment accumulations were observed behind the windrows but they probably kept water from building enough volume and velocity to cause erosion, especially during the first four critical months when ground cover was at a minimum. Root raking was done carefully to minimize soil disturbance and the windows were not burned. Second, regrowth of vegetation on the watershed was rapid. Douglass and Goodwin (1980) concluded that ground cover was the single most important variable that influenced soil losses after mechanical site preparation in the North Carolina Piedmont. Third, a buffer area was left around the live stream. This untreated area extended about 66 feet on each side of the live stream and encompassed the extensions of the live stream channels during normal storm events.

In general, sediment losses reported here are much less than those reported following mechanical site preparation on the more erodible soils in the South. Douglass and Goodwin (1980) reported that a shearing, windrowing, and burning treatment on four small watersheds in the Piedmont of North Carolina produced first-year average annual soil losses of 3,123 lb/acre. Average annual sediment losses on two watersheds subjected to a similar treatment in Arkansas were higher the second year (1,342 lb/acre) than the first year (714 lb/acre) because of four large storms that accounted for 88 percent of total sediment yield the second year (Beasley et al. 1986).

## STREAMFLOW CHEMISTRY

Figure 5 indicates a 28-percent increase in average annual specific conductance after site preparation. Of the chemical constituents tested, only $NO_3$-N showed an increase in quarterly losses (Fig. 6). The difference between measured and computed losses was about 1.5 lb/acre/yr. These results generally agree with the minor changes in streamflow chemistry that occurred after a watershed was clearcut on the Fernow Experimental Forest (Patric 1980). Even those minor increases lasted only 3 years.

No major increase in nutrient losses was anticipated after the site-preparation treatment. The soils on this watershed are nutrient-poor after many years of farming. Soil base saturation averages only 5 percent and cation exchange capacity only 13 percent. The buffer strip around the stream provided an opportunity for nutrients leached from the treated area to be used by vegetation on the strip. Finally, as indicated by Table 1, native plants quickly reclaimed the site and prevented long-term nutrient leaching.

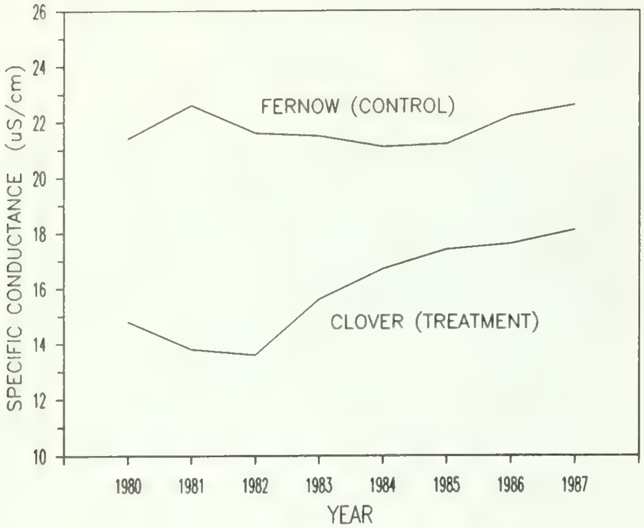


Figure 5.--Time trends of specific conductance in streamflow from control and treated watersheds.

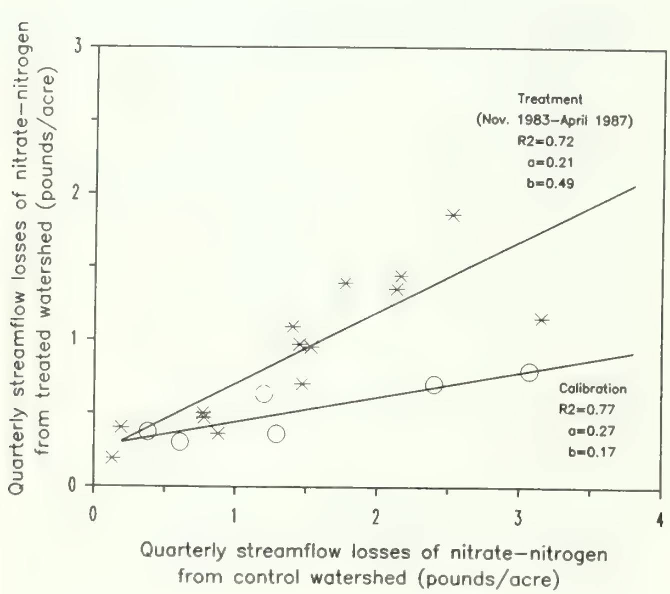


Figure 6.--Changes in $NO_3$-N following site preparation on Clover watershed.

STREAM TEMPERATURE

Of the 48 weekly growing-season observations after site preparation, 33 were greater than predicted by calibration data, 10 were less than predicted, and 5 were equal. The maximum positive deviation from the regression was $5^{o}$F and the maximum stream temperature measured during the calibration and treatment periods were $66^{o}$F and $69^{o}$F, respectively. Although the records indicate a slight increase in stream temperature after site preparation, the increases were not significant at the 95-percent confidence level. Swift and Messer (1971) evaluated changes in water temperature at the Coweeta Hydrologic Laboratory caused by forest removal in terms of requirements by brook trout. They stated that stream temperature should not exceed $68^{o}$F for optimum trout habitat. Although the stream in the treated watershed is too small to support a trout population, the maximum temperature ($69^{o}$F) exceeded the optimum value for brook trout only twice.

Several investigators have reported that stream temperature was unaffected by forest harvest when streamside vegetation was left to shade the channel (Swift and Messer 1971; Levno and Rothacher 1967). Since a 66-foot-wide strip on each side of the stream channel was excluded from the site-preparation treatment, it is not surprising that increases in stream temperature in this study were not significant.

WATER YIELD

Water yield increased significantly (0.95 level) by 3.9, 2.8, and 1.5 inches during the first, second and third growing seasons after site preparation, respectively. No yield increases were detected during the dormant season.

The increases were slightly smaller than those reported for deforestation treatments on other Fernow Experimental watersheds (Kochenderfer and Aubertin 1975). Those authors reported a growing-season yield increase of about 4.5 inches during the first year after a commercial clearcut that removed 75 percent of the basal area and about 6.5 inches during the first year after all trees larger than 1 inch d.b.h. were harvested. Water yield returned to pretreatment levels within 5 years after the cuttings. Rapid revegetation was responsible for the short-term treatment effect on growing-season water yield.

CONCLUSIONS

A mechanical site-preparation treatment applied to a 28.6-acre watershed in the central Appalachians resulted in a slight increase in both water yield during the growing season and annual losses of $NO_3$-N. Sediment losses were slightly, but not significantly, greater after the site preparation compared to calibration values. Maximum and minimum weekly stream temperatures did not change significantly due to treatment. The relatively small effects of this treatment are attributed to (1) building roads on the contour well away from the stream, and windrowing the slash either in them or on the contour: (2) using care during root raking to minimize soil disturbance and not burning windrows: (3) rapid revegetation of the areas: and (4) the moderating effect of the 3.5-acre buffer area left around the stream.

We conclude that mechanical site preparation, as practiced in this study, is a hydrologically acceptable practice.

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NUTRIENT INPUTS AND POOLS IN UPLAND AND BOTTOMLAND FORESTS

OF ALLERTON PARK, ILLINOIS[1]

Mark B. David[2]

Abstract.--Inputs of base cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$), $NO_3^-$, $NH_4^+$, $SO_4^{2-}$, $Cl^-$, dissolved organic carbon (DOC) and $H^+$ were examined in upland and bottomland sites in east-central Illinois. Soil pools of base cations and exchangeable $Al^{3+}$ and $H^+$ were also determined. Litterfall added large amounts of N, S, and organic materials (e.g. 11.2 and 7.1 kg S/ha/yr in bottomland and upland sites, respectively). Inputs of sulfate by throughfall were 14.8 and 15.2 kg S/ha/yr in bottomland and upland sites, respectively, corresponding to 27 and 11% of the 0-60 cm soil sulfate pool. Throughfall was dominated by base cations (primarily $Ca^{2+}$ and $K^+$), sulfate, and nitrate. Upland soils had low levels of $Ca^{2+}$ and $Mg^{2+}$ and similar levels of $K^+$ compared to the bottomland soil (e.g. 1-5 and 19-26 meq $Ca^{2+}$/100 g in upland and bottomland soils, respectively). Exchangeable $H^+$ and $Al^{3+}$ levels were also greater in the more acid upland soils, in comparison to the bottomland (1-5 and 0.05-0.1 meq total acidity/100 g soil in upland and bottomland soils, respectively). Each forest requires different management with respect to nutrient availability and possible fertilization requirements.

## INTRODUCTION

Nutrients are added to forest soils through several mechanisms including: litterfall, root litter, throughfall, stemflow, root exudates, and periodic flooding. All can add to the pool available for plant uptake, although some inputs require subsequent mineralization (e.g. litterfall).

Peterson and Rolfe (1982a, 1982b) examined inputs of nitrogen, potassium, calcium, magnesium, and phosphorus via litterfall, stemflow, and throughfall in upland and bottomland forests of central Illinois. Although bottomland and upland litterfall were similar in terms of dry mass and most nutrients, both were greater than comparable temperate forests (Peterson and Rolfe 1982a). They did find greater litter decomposition in the bottomland site compared to the upland. Their examination of solution inputs indicated that for the elements studied the contribution to the forest floor was small compared to organic inputs via litterfall, with the exception of potassium (Peterson and Rolfe 1982b). This work also pointed out that differences in species characteristics and variability in the physical environment produced contrasting patterns of nutrient transfer (Peterson and Rolfe 1982a).

The purpose of the present work was to expand on results obtained earlier at upland and bottomland forests in Illinois by examining similar processes and including additional nutrients, primarily sulfur. The objectives of this project were to: 1) quantify inputs of dry mass, sulfur, and nitrogen through litterfall; 2) determine inputs of anions and cations in throughfall; and 3) relate these inputs to soil pools of nutrients.

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## STUDY SITES

Bottomland and upland sites previously studied at Robert Allerton Park were utilized in this study. The park is located along the Sangamon River in east-central Illinois. A detailed description can be found in Peterson and Rolfe (1982a) and Bartel-Ortiz and David (1988).

Silver maple (Acer saccharinum L.) dominates the floodplain site, whereas black and northern red oak (Quercus velutina Lam. and Q. rubra L.) dominate upland sites. Basal areas were 52.0 and 31.8 $m^2$ $ha^{-1}$ for the bottomland and upland sites, respectively in 1986 (Bartel-Ortiz and David 1988). Peterson and Rolfe (1982a) classified upland soils in this area as Russell silt loam (fine-silty, mixed, mesic Typic Hapludalfs) and Martinsville silt loam (fine-loamy, mixed, mesic Typic Hapludalfs). Bottomland soils primarily consisted of Sawmill silty clay loam (fine-silty, mixed mesic Cumulic Haplaquolls).

## METHODS

### Field Sampling

After a 0.1 ha circular plot was established on each upland and bottomland site, a 20m x 20m area was centered and divided into 2m x 2m subplots. Soil samples were collected at four depths in the summer of 1986 (0-10, 10-30, 30-60, and $60^+$ cm) from pits excavated at five randomly selected points in each plot. Twelve and six funnel (15.5 cm diameter) throughfall collectors were randomly located in the upland and bottomland sites, respectively. Upland collectors were 0.3 m from the ground, whereas the bottomland were 2 m so that they were above flood waters. Collectors were sampled every 2-3 weeks, depending on rainfall. During the winter 8.5 cm diameter plastic cups were used as snow collectors, with samples collected monthly. Bulk precipitation was also collected in an open area of the Park using two collectors. Collections were made from October 1986 through September 1987. River water samples from the Sangamon were obtained whenever throughfall was collected.

Litterfall was collected in twelve and six 0.5 x 0.5 m traps that were randomly located in the upland and bottomland sites, respectively. Traps were constructed from wood frames and fiberglass window screening. Samples were collected periodically from October, 1986 to December, 1987. This included two fall periods which were averaged for yearly flux calculations.

### Analytical Techniques

Soil samples were air-dried and sieved (2 mm) before analysis. Litterfall was sorted into leaves, reproductive parts, and wood (only leaf data reported here), dried for 48 hours at $65^{\circ}C$, and ground to pass a 20 mesh sieve in a Wiley Mill. Volume of the throughfall and precipitation was determined by weighing or volume, and all solutions were filtered through GF/C glass fiber filters.

Exchangeable cations were determined using unbuffered $NH_4$-Cl, with cations in extracts determined by atomic absorption (Robarge and Fernandez 1986). Exchangeable acidity was measured by titrating unbuffered 1N KCl extracts to a phenolphthalein endpoint (Robarge and Fernandez 1986). Base saturation was calculated by summing base cations and dividing by this sum plus exchangeable $H^+$ and $Al^{3+}$. Soil content of cations was determined using bulk densities from Bartel-Ortiz and David (1988).

Total S in litter was determined using a LECO SC-132 S analyzer (David et al. 1988). Litter total N was determined by Kjeldahl digestion with ammonium in digests measured using a Wescan Ammonia Analyzer. Solution anions (sulfate, nitrate, and chloride) were determined by ion chromatography, cations by atomic absorption, dissolved organic carbon using a Dohrmann DC-80 analyzer, pH potentiometrically, and ammonium using a Wescan Ammonia Analyzer. Volume weighted averages were used for all solution summaries of precipitation and throughfall.

## RESULTS AND DISCUSSION

### Litterfall

During the 14 months litterfall was collected, leaf litter averaged 3828 and 5284 kg/ha/yr in the bottomland and upland sites, respectively (table 1). Peterson and Rolfe (1982a) found similar levels of litterfall at both sites during 1978 and 1979 (2-year means of 3846 and 5213 kg/ha/yr for bottomland and upland sites, respectively).

Although dry mass deposition of leaves was less in the bottomland site, S concentrations were much greater leading to greater S inputs (table 1). Total S ranged from 0.161 to 0.532% and 0.097 to 0.224% in bottomland and upland sites, respectively. Annual inputs of leaf S were 11.2 and 7.1 kg S/ha/yr, indicating the large difference in leaf S inputs to the forest floor. Litterfall S inputs for a chestnut oak forest in Tennessee and a northern hardwood forest in the Adirondack Mountains of New York were 10 and 4.7 kg S/ha/yr, respectively (Johnson et al. 1982; David et al. 1987).

Nitrogen inputs were 56 kg N/ha/yr in the bottomland site, and 54 in the upland. Peterson and Rolfe (1982a) observed similar or greater inputs of P, K, Ca, Mg, and Na and smaller inputs of N in litter in the upland versus the bottomland site. Their values for N were 54 and 49 kg N/ha/yr for bottomland and upland sites, respectively.

and total S and N concentrations and mass at bottomland and upland sites.

| Collection Date | Dry Mass | %S | kg S/ha | %N | kg N/ha |
|---|---|---|---|---|---|
| Bottomland | | | | | |
| 4 Nov | 2031 | 0.262 | 5.3 | 1.51 | 30.7 |
| 18 Nov | 852 | 0.223 | 1.9 | 1.36 | 11.6 |
| 10 Mar | 164 | 0.188 | 0.3 | 1.94 | 3.2 |
| 20 May | 17 | 0.532 | 0.1 | 4.07 | 0.7 |
| 28 Jul | 140 | 0.328 | 0.5 | 2.49 | 3.5 |
| 30 Sep | 486 | 0.388 | 1.9 | 1.37 | 6.7 |
| 2 Nov | 2914 | 0.318 | 9.3 | 1.30 | 37.8 |
| 9 Dec | 247 | 0.161 | 0.4 | 1.66 | 4.1 |
| Upland | | | | | |
| 4 Nov | 2768 | 0.153 | 4.2 | 1.02 | 28.1 |
| 18 Nov | 1230 | 0.115 | 1.4 | 0.76 | 9.5 |
| 10 Mar | 437 | 0.126 | 0.6 | 0.98 | 4.3 |
| 20 May | 33 | 0.224 | 0.1 | 2.32 | 0.8 |
| 28 Jul | 114 | 0.192 | 0.2 | 2.23 | 2.5 |
| 30 Sep | 502 | 0.154 | 0.8 | 1.43 | 7.2 |
| 2 Nov | 2867 | 0.136 | 3.9 | 0.95 | 27.2 |
| 9 Dec | 1531 | 0.097 | 1.5 | 0.86 | 13.2 |

The higher concentration of S and N in bottomland leaf litter probably reflects the large pools of total S and N found in this soil (Peterson and Rolfe 1982b; Bartel-Ortiz and David 1988). Because of inputs of organic matter from flood events, the bottomland site is richer in both of these elements. Peterson and Rolfe (1982b) measured total N contents of 16540 and 6530 kg N/ha for the 0-60 cm soil depth in bottomland and upland sites, respectively, whereas Bartel-Ortiz and David (1988) measured corresponding total S contents of 3072 and 1353 kg S/ha. Inasmuch as S and N cycling is closely coupled, increased N uptake by the bottomland forest in comparison to the upland would also increase S uptake.

Wet only precipitation chemistry is available from a nearby (30 km) NADP station at Bondville, Illinois. Volume weighted mean chemistry for the period 1980-1984 is shown in figure 1. Wet deposition is dominated by sulfate and $H^+$, with smaller concentrations of nitrate and ammonium. Because of exposure to dust and other dry components and gases, bulk precipitation collected at Allerton Park shows increased concentrations of most elements, particularly base cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$) and sulfate (fig. 1).

After passage of precipitation through the bottomland and upland canopies, large increases in base cations and sulfate were found (fig. 1). Hydrogen ion was also neutralized, with little change in chloride, ammonium, or nitrate concentrations. This increase in cations and sulfate may be from two processes: 1) washoff of dust deposited on foliage; and 2) leaching of foliage. For $K^+$, leaching is known to be an important process. Little difference in throughfall chemistry was observed between sites, a similar finding to that of Peterson and Rolfe (1982b). Calcium was the dominate base cation, followed by $K^+$, $Mg^{2+}$, and $Na^+$.

The imbalance between anions and cations in throughfall suggests that other anions are present in the solutions. Both organic anions and bicarbonate are probably present. Dissolved organic carbon concentrations averaged 756 and 735 µmol C/L in the bottomland and upland throughfall, and could contribute large amounts of organic anions (table 2).

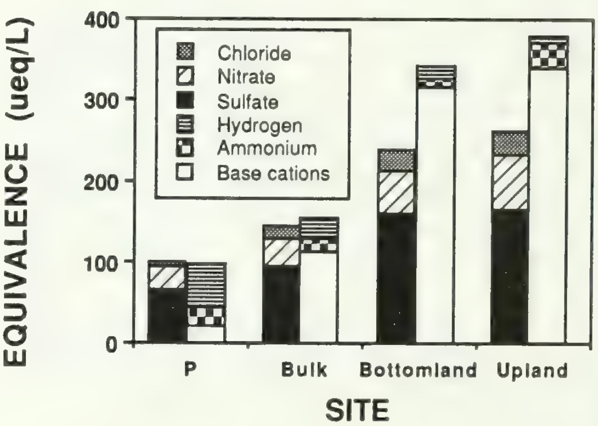


Figure 1.—Charge distribution in precipitation collected at Bondville, IL, bulk precipitation, and bottomland and upland throughfall at Allerton Park. Base cations are the sum of $Ca^{2+}$, $Mg^{2+}$, $K^+$, and $Na^+$ equivalence.

Table 2.--Volume weighted concentrations of dissolved organic carbon (μmol/L) in throughfall at bottomland and upland sites.

| Sample | Mean | Range |
|---|---|---|
| Bottomland Throughfall | 756 | 237 - 1460 |
| Upland Throughfall | 735 | 274 - 2022 |

Deposition of ions follows the same pattern as concentration, and illustrates the amounts of ionic inputs to the forest floor (fig. 2). Sulfate inputs were 617, 925, 948 eq/ha/yr in bulk precipitation and bottomland and upland throughfall, respectively. On a kg S/ha/yr basis corresponding values are 9.9, 14.8, and 15.2, respectively. These data suggest a large increase in S as a result of canopy washing and leaching.

## Sangamon River

Another input to the bottomland site is the Sangamon River, which usually floods the site for several months each year. Peterson and Rolfe (1982c) measured sedimentation inputs for several elements, and showed this was an important input. Water chemistry suggests that for many elements flooding and diffusion of elements into the soil solution may also be a significant input (table 3). Very high concentrations of all elements except $K^+$ and ammonium are found in river water. It is not possible to calculate inputs from this source, but the potential is there for substantial additions.

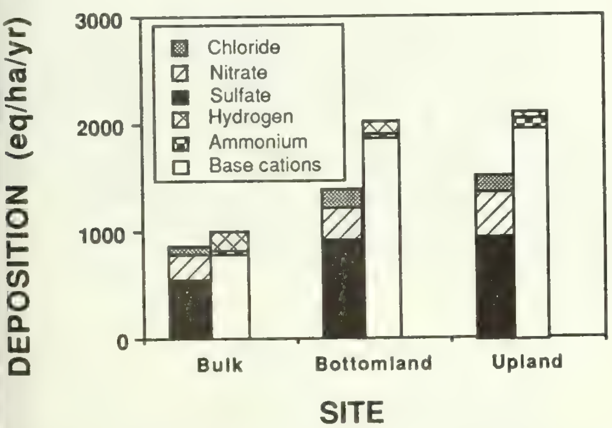


Figure 2.--Charge distribution in bulk deposition and bottomland and upland throughfall at Allerton Park. Base cations are the sum of $Ca^{2+}$, $Mg^{2+}$, $K^+$, and $Na^+$ equivalence.

Table 3.--Concentrations of anions and cations in the Sangamon River sampled at Allerton Park, Illinois (units are μeq/L).

| | Mean | Range |
|---|---|---|
| pH | 8.2 | 7.6 - 8.5 |
| $Ca^{2+}$ | 3346 | 1344 - 3969 |
| $Mg^{2+}$ | 2347 | 1041 - 3076 |
| $K^+$ | 49 | 22 - 102 |
| $Na^+$ | 594 | 150 - 1481 |
| $NH_4^+$ | 6 | 1 - 15 |
| $SO_4^{2-}$ | 830 | 485 - 1088 |
| $NO_3^-$ | 429 | 74 - 928 |
| $Cl^-$ | 856 | 483 - 1514 |

## Soil Pools

Cation levels are strikingly different between the sites (table 4). The upland site is an acidic Alfisol, with low concentrations of cations and large amounts of exchangeable $Al^{3+}$. Base saturations range from 33.5 to 91.5% however, indicating that although the cation pool is small, base cations still dominate. In the bottomland soil, levels of $Ca^{2+}$ and $Mg^{2+}$ are much greater, $K^+$ about the same, and exchangeable $Al^{3+}$ and $H^+$ lower. Base saturations are all greater than 99%. This difference between the sites can be attributed to annual flooding of the bottomland site with $Ca^{2+}$ and $Mg^{2+}$ rich river water along with particle sedimentation. Soil pH (0.01 M $CaCl_2$) reflects the cation levels and base saturation ranging from 6.3 - 6.8 and 3.7 - 4.5 in bottomland and upland soils, respectively (Bartel-Ortiz and David 1988).

Table 4.--Soil exchangeable cations at bottomland and upland sites.

| Depth (cm) | $Mg^{2+}$ | $Ca^{2+}$ | $K^{+}$ | $Al^{3+}$ | $H^{+}$ | % Base Sat |
|---|---|---|---|---|---|---|
| | ------------ meq/100 g ---------- | | | | | |
| Bottomland | | | | | | |
| 0-10 | 9.7 | 25.6 | 0.3 | 0.04 | 0.06 | 99.7 |
| 10-30 | 9.1 | 23.2 | 0.3 | 0.04 | 0.03 | 99.8 |
| 30-60 | 8.1 | 20.0 | 0.2 | 0.03 | 0.02 | 99.8 |
| 60-90 | 7.6 | 18.8 | 0.2 | 0.06 | 0.00 | 99.8 |
| Upland | | | | | | |
| 0-10 | 1.1 | 3.8 | 0.2 | 0.41 | 0.05 | 91.5 |
| 10-30 | 0.4 | 1.1 | 0.1 | 2.54 | 0.62 | 33.5 |
| 30-60 | 2.3 | 2.4 | 0.2 | 4.16 | 0.55 | 50.9 |
| 60-100 | 4.2 | 5.3 | 0.2 | 2.48 | 0.64 | 75.7 |

The content of exchangeable cations illustrates the large pool size of $Ca^{2+}$ and $Mg^{2+}$ in the bottomland soils (table 5). For the top 0-60 cm of mineral soil $Ca^{2+}$ and $Mg^{2+}$ pools are 1736 and 687 versus 207 and 143 keq/ha for the bottomland and upland soils, respectively. Potassium is remarkably similar between the sites (16 - 18 keq/ha), suggesting little input from river water or sediments. Concentrations of $K^{+}$ were similar at both sites to levels determined by Peterson and Rolfe (1982c). Bottomland concentrations also were similar for $Ca^{2+}$ and $Mg^{2+}$. However, these latter two cations were only about half the values they reported. This could be attributed to seasonal variation in cation concentrations illustrated by Peterson and Rolfe (1982c, 1985) for these sites.

### Elemental Cycling of S

Inputs of S by litterfall and throughfall add large amounts of this element to the soil (26.0 and 22.3 kg S/ha/yr for bottomland and upland sites, respectively). Total S pools in the soil (0-60 cm) were estimated at 3072 and 1353 kg S $ha^{-1}$ in the bottomland and upland, respectively, with sulfate pools of 54 and 71 kg S/ha (Bartel-Ortiz and David 1988). Throughfall is an important source of sulfate, adding 27 and 11% of the soil sulfate annually for the bottomland and upland sites, respectively. Additional sulfate is probably made available through mineralization of organic S as well (Bartel-Ortiz and David 1988).

Table 5.--Content of soil exchangeable cations at bottomland and upland sites.

| Depth (cm) | $Mg^{2+}$ | $Ca^{2+}$ | $K^{+}$ | $Al^{3+}$ | $H^{+}$ |
|---|---|---|---|---|---|
| | ------------ keq/ha ------------ | | | | |
| Bottomland | | | | | |
| 0-10 | 112 | 296 | 4 | 0.4 | 0.7 |
| 10-30 | 247 | 630 | 7 | 1.0 | 0.9 |
| 30-60 | 327 | 809 | 7 | 1.1 | 0.7 |
| 60-90 | 282 | 697 | 6 | 2.2 | 0.0 |
| Sum | | | | | |
| (0-60) | 687 | 1736 | 18 | 2.5 | 2.3 |
| Upland | | | | | |
| 0-10 | 14 | 52 | 2 | 5.6 | 0.7 |
| 10-30 | 13 | 34 | 4 | 81 | 20 |
| 30-60 | 116 | 122 | 10 | 211 | 28 |
| 60-100 | 246 | 307 | 14 | 145 | 38 |
| Sum | | | | | |
| (0-60) | 143 | 207 | 16 | 298 | 48 |

## CONCLUSIONS

Inputs of elements to bottomland and upland soils are similar for throughfall but different for leaf litter S. Bottomland soils are strongly influenced by inputs from the Sangamon River, which annually floods the site. This increases soil pH, and exchangeable $Ca^{2+}$ and $Mg^{2+}$, compared to the upland soil. Large amounts of sulfate are added to the soil by throughfall in comparison to soil pools. For other elements, proportions are much smaller. Because of large differences in soil pools and inputs, each forest requires different management with respect to nutrient availability and possible fertilization requirements.

## ACKNOWLEDGEMENTS

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EFFECTS OF PREVIOUS STAND MANAGEMENT ON MORTALITY

FOLLOWING GYPSY MOTH DEFOLIATION[1]

Kurt W. Gottschalk[2]

Abstract.--The question of whether intermediate stand treatments and the timing of those treatments relative to the time of defoliation increases or decreases the vulnerability of those stands to the gypsy moth has been addressed. The primary objective was to determine if past management practices, especially thinnings, increases or decreases the mortality that occurs when these stands are subsequently defoliated by the gypsy moth. A secondary objective was to determine if the timing of such treatments relative to defoliation changes this mortality response. Study sites were selected on three adjoining forest districts in Central and South-Central Pennsylvania and Western Maryland in the Ridge and Valley province. Stands were identified as to type and timing of treatment through information available in the states' forest management records. Defoliation intensity and frequency were delineated using either infrared optical-bar photography or aerial sketch maps. Selected stands were then classified by defoliation history and time of silvicultural treatment. Each plot consists of a forest stand or management unit ranging from 10 to 90 acres.

Study design was a split block with time of treatment (uncut, 1-3, 4-6, 7-10, 10-15, >15 years predefoliation, and 1-3 years postdefoliation) as the main plot split by defoliation classes (defoliated or undefoliated). Defoliation frequency and site factors are covariants in the analysis. Orthogonal contrasts were used to test specific hypotheses. Each stand was sampled using variable radius plots. A minimum of 15 plots were taken in each stand with additional plots added as necessary to assure accuracy to within 10 percent of the mean. Data was recorded using SILVAH data collection protocol for all live and standing dead trees larger than one inch dbh. Two regeneration plots were recorded for each overstory plot. Stand summaries were computed using the SILVAH computer program (V. 2.3). Stand summary values were used as the variables in statistical analysis.

Preliminary analyses indicate significant differences in mortality (percent of basal area) between defoliation classes within treatment classes. Mortality levels were also highly significant between treatment classes within defoliation classes in all of the undefoliated stands but only in two classes within the defoliated stands. Mortality increased in direct response to the number of defoliations a stand experienced. Mortality was higher in the pole size class in undefoliated stands, while defoliated stands have greatest mortality in the medium and large sawtimber classes. Mortality in uncut, undefoliated stands averaged 12.1 percent, while undefoliated, thinned stands ranged from 3.6 to 7.2 percent. Mortality in uncut, defoliated stands averaged 30.9 percent, while defoliated, thinned stands ranged from 8.4 to 48.5 percent.

Reanalysis using defoliation frequency and intensity instead of thinning treatments resulted in a better explanation of the variation (>90 percent). Due to this confounding variable, additional stands will be measured in a factorial design of thinning treatments and defoliation classes to account for the confounding. Collection of additional data will be completed in 1988, pooled with the previous data, and new analysis conducted. The results have direct bearing to the timing and application of thinnings to oak stands in relation to gypsy moth defoliation.

Keywords: oak-hickory forest type, thinning, tree mortality, Lymantria dispar L.

[1]Poster presented at the Seventh Central Hardwood Forest Conference, Southern Illinois University, Carbondale, March 5-8, 1989.

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## A KEY FOR HARDWOOD TREE GRADING[1]

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### INTRODUCTION TO THE TGA

This paper presents a new method for assisting in the grading of hardwood trees. This method employs a tree grading algorithm (TGA) developed from grading criteria in "Hardwood Tree Grades for Factory Lumber" USFS NE-333 (see paper by Liu et al. this volume). The TGA system is formatted as a series of 23 questions. Grading can be accomplished by following the questions in a step-by-step manner. This algorithmic grading system differs from other tree grading keys in two fundamental ways: first, it is a true algorithm using significantly fewer steps, and second, once form class has been established it alleviates the need for consulting tables or charts for upper stem diameters.

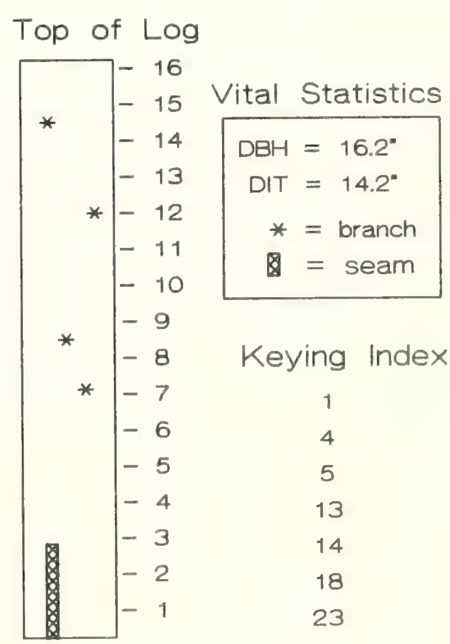
The grader executes the TGA by evaluating a statement and determining if it is true or false. The grader branches to another statement according to the answer received. The user repeats this evaluation-branching activity until the tree grade is obtained. We believe this key, as is true for others, may be particularly helpful in training activities. This poster summary paper presents the TGA system and an example grading face for demonstating the use of this key for hardwood tree grading.

**HARDWOOD TREE GRADING KEY**

| | Statement | 12' | 14' | 16' | Cuttings | YES/NO |
|---|---|---|---|---|---|---|
| 1. | DBH ≥ 15.6" (14.6" FOR BASSWOOD & ASH) | | | | | 4/2 |
| 2. | DBH ≥ 12.6" | | | | | 7/3 |
| 3. | DBH ≥ 9.6" | | | | | 10/BG |
| 4. | DIT ≥ 19.6" | | | | | 11/5 |
| 5. | DIT ≥ 15.6" | | | | | 12/6 |
| 6. | DIT ≥ 12.6" (11.6" FOR BASSWOOD & ASH) | | | | | 13/7 |
| 7. | DIT ≥ 11.6" | | | | | 15/8 |
| 8. | DIT ≥ 10.6" | | | | | 16/9 |
| 9. | DIT ≥ 9.6" | | | | | 17/10 |
| 10. | DIT ≥ 7.6" | | | | | 18/BG |
| | | 12' | 14' | 16' | length of grading section | |
| 11. | SCC ≥ | 10' | 11'8" | 13'4" | 1 or 2 CC--each ≥ 3' | 20/14 |
| 12. | SCC ≥ | 10' | 11'8" | 13'4" | 1 or 2 CC--each ≥ 5' | 20/14 |
| 13. | SCC ≥ | 10' | 11'8" | 13'4" | 1 or 2 CC--each ≥ 7' | 20/14 |
| 14. | SCC ≥ | 8' | 9'4" | 10'8" | 1, 2, 3 CC--each ≥ 3' | 19/18 |
| 15. | SCC ≥ | 8' | 9'4" | 10'8" | 1, 2, 3 CC--each ≥ 3' | 22/19 |
| 16. | SCC ≥ | 8' | 9'4" | 10'8" | 1 or 2 CC--each ≥ 3' | 22/19 |
| 17. | SCC ≥ | 10' | 11'8" | 13'4" | 1 or 2 CC--each ≥ 7' | 22/19 |
| 18. | SCC ≥ | 6' | 7' | 8' | all CC ≥ 2' | 23/BG |
| 19. | TCD ≤ 9% or [9% <Rot ≤ 40%, no S&C or SD] | | | | | G2/23 |
| 20. | TCD ≤ 9% | | | | | G1/21 |
| 21. | S&C ≤ 15% and TCD ≤ 40% | | | | | G2/23 |
| 22. | TCD ≤ 9% | | | | | G2/23 |
| 23. | TCD ≤ 50% | | | | | G3/BG |

### GRADING EXAMPLE USING THE TGA

Use the general TGA to assign a grade to the grading face diagram. This diagram represents the defect location on the grading face of a scarlet oak. Starting with statement one follow the sequence according to the answer obtained. The scarlet oak has a DBH of 16.2", thus the statement is evaluated yes. Proceed to statement 4. Since the upper stem diameter is less than 19.6" the TGA proceeds through statements 4 and 5. Statement 6 is evaluated yes and the grading proceeds to statement 13. The grading face diagram shows 2 clear cuttings, the first between 3 and 7 feet and the second between 8.5 and 11.5 feet, for a total of 7 feet in two cuttings in a 12 foot grading section. Using this information the TGA branches through statement 13 and 14 to 18. This statement is evaluated yes and the TGA moves to statement 23 which is evaluated yes and yields grade 3.

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CLASSIFICATION AND EVALUATION OF THE NATCHEZ TRACE STATE FOREST, STATE RESORT PARK, AND WILDLIFE MANAGEMENT AREA FOR TIMBER AND WILDLIFE HABITAT[1]

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ABSTRACT

The 45,000-acre Natchez Trace State Forest, Park, and Wildlife Management Area (NTSF) began as a land reclamation project of the Resettlement Administration in 1935. The State of Tennessee acquired ownership in 1955. Smoother ridges, moist bottoms, and some slopes were cleared, row-cropped, and pastured resulting in extensive sheet and gully erosion of the fragile soils. Mixed oak forests dominate the uplands that were not cleared; loblolly pine plantations occupy the former gullied cropland. Bottomland hardwoods occur in the wet bottoms; some ponded areas support alder thickets. Most of the erosion has been controlled. Upland soils are derived from a 2 to 3-foot cap of loess and/or the underlying loamy and clayey unconsolidated Coastal Plain sediments.

A land classification system has been developed as part of the overall land management planning process. The landscape was divided into eighteen landtypes based on the differences in geology, topography, soils, and vegetation. Landtypes are described in terms of nine elements (geographic setting, dominant soils, parent material, solum thickness, surface soil texture, internal soil drainage, relative soil water supply, soil fertility, and vegetation). Each landtype is evaluated in terms of productivity (site index and mean annual cubic growth) and desirability (most desirable, acceptable, and least desirable) of selected hardwoods and conifers for timber production, and for suitability as wildlife habitat. Also, each landtype is rated for five problems (plant competition, seedling mortality, equipment limitations, erosion hazard, and windthrow hazard,) that can affect forest management operations. The resulting landtype map is one element of the physical and biological information about NTSF that is stored on an ESRI (Environmental Systems Research Institute) Geographic Information System.

The land classification system permits the intensive study of the relationships between forest plant communities and the landscape units. The ultimate goal of such a study is the capability of predicting which community(s) grow on each unit and to ascertain the successional pathways resulting from various forest cuttings. Once plant-landscape relationships are known, land managers can easily and economically determine wildlife habitat parameters.

Although the land classification was developed just for NTSF, it is applicable to an estimated 1 to 2 million acres in West Tennessee, northeast Mississippi, and northwest Alabama.

Key words: Forest land classification, site productivity, erosion, timber management, wildlife habitat, Upper East Gulf Coastal Plain, West Tennessee.

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# A MULTIFACTOR CLASSIFICATION OF UPLAND HARDWOOD FOREST ECOSYSTEMS OF THE KICKAPOO RIVER WATERSHED, SOUTHWESTERN WISCONSIN[1,2]

David M. Hix, Craig G. Lorimer,
and Raymond P. Guries[3]

A multifactor classification of upland hardwood forest ecosystems has been developed for the Kickapoo River watershed. Because the forests of southwestern Wisconsin have been significantly altered by past cutting and grazing, an ecological approach was used that integrates landform, soil, and vegetation. Twenty-one ecosystem units have been characterized based on a sample of 87 plots. Each ecosystem unit can be distinguished by its unique combination of aspect, slope position and steepness, parent material depth and type, and vegetation (canopy tree species and groups of ground cover species). These ecosystem units ranged in estimated productivity (average site index in feet for northern red oak) from good (69) to poor (41), with most units intermediate or average (49-56). Most ecosystem units are dominated by combinations of northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and sugar maple (*Acer saccharum* Marsh.). Northern red oak tends to dominate the most productive units. Ecosystem units with northeast aspects are dominated by sugar maple and basswood (*Tilia americana* L.), while white oak is most common on southwest-facing units of intermediate productivity. Discriminant analysis of the eleven most common ecosystem units using a combination of environmental and vegetational variables correctly classified the ecosystem unit in 97% of the cases. The classification is being used as a research framework, i.e., advance regeneration and early stand development patterns are being evaluated within selected ecosystem units.

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# EFFECTS OF UNDERSTORY CONTROL ON SURVIVAL AND VIGOR OF RED OAK SEEDLINGS BENEATH A SHELTERWOOD[1,2]

D. M. Pubanz, C. G. Lorimer, and R. P. Guries[3]

## INTRODUCTION

Slow growth of oak seedlings compared to growth of competing vegetation is generally recognized as a major cause of oak regeneration failures. Clearcuts often fail to regenerate to oak because established vegetation responds more readily to abundant light and moisture than young, natural oak seedlings or transplants (Loftis 1979, McGee and Loftis 1986). Recent regeneration trials in Missouri have shown that a high density shelterwood may stimulate the vigor of planted oak seedlings without giving an undue competitive advantage to other species (Johnson 1984). Silvicultural prescriptions based on these findings have been formulated for the Missouri Ozarks (Johnson et al. 1986).

The labor and expense of intensive oak regeneration practices may be an obstacle in areas where most woodlots are held by small, private landowners. This study was designed to determine if adequate oak regeneration can be obtained when only some of the recommended cultural treatments are made. This approach includes the option of relying wholly or in part on natural regeneration of oak. The present paper presents two-year results from shelterwood-herbicide-underplanting trials on two sites in the Kickapoo Valley of southwest Wisconsin.

## STUDY AREAS AND METHODS

Both study areas are located on sites of above-average productivity with mature stands in which oak species comprise > 50% of the overstory basal area. The first site, near an intermittent stream (Harris Creek), is located on a lower east-facing slope with deep, silt loam soil, and has a site index of about 70 for red oak. The second site, near Warner Creek, is situated on a middle WNW-facing slope with a deep, colluvial sandy loam soil. The Warner Creek site is somewhat drier than the Harris Creek site (site index about 62), but is capable of producing good quality red oak sawtimber.

Treatments applied at each site were: (1) foliar application of glyphosate (Roundup) herbicide to all low vegetation ($\leq$ 1.5 m tall) in late summer 1985; (2) shelterwood cut to 70% residual crown cover, with cutting of all understory trees > 1.0 m tall and treatment of stumps with Tordon RTU to prevent resprouting (winter-spring 1986); and (3) underplanting of 1-0 red oak bare-root nursery stock at a density of 2470/ha in the spring of 1986. Seedlings had been undercut in the nursery but not shoot-pruned. At the time of planting, mean basal shoot diameter was 5.9 mm and mean shoot length was 34.7 cm. All possible combinations of treatments, including controls for each treatment, were tested in a replicated split-split plot experimental design.

Percentage ground area covered by herbs, shrubs, and tree seedlings was measured in May, July, and September of each year with a Plexiglas grid mounted in a wood frame. Height measurements on planted seedlings were made in early August. Numbers of first-order branches and numbers of leaves were also recorded as an indicator of oak seedling vigor.

## RESULTS

### Treatment Effects on Low Vegetation

Groundcover herbicide treatment and shelterwood cutting had opposite effects on the subsequent density of low vegetation. In summer and fall of 1986, glyphosate treatment decreased cover of low vegetation 81% compared to controls while cutting increased cover by 15%. Plots that were both cut and herbicided had 37% less coverage by low vegetation than controls. In the second year after treatment, herbicide effects had diminished considerably. Herbicided plots had from 10-23% less coverage of low vegetation than unherbicided plots at Harris Creek, and 37-44% less at Warner Creek. At Harris Creek, the herbicide effect was significant only in the fall, while herbicide effects at the drier Warner Creek site were still significant in all seasons.

### Oak Seedling Survival

At the end of the second growing season following treatment, survival of planted oak seedlings ranged from 73-85% on uncut plots and > 95% on cut plots on both sites. Herbicide treatment of the low vegetation, however, had no significant effect on planted seedling survival.

In the first year after treatment, cut-herbicided plots had substantially higher densities of natural red oak seedlings than control plots, although the difference was statistically significant only at the moister Harris Creek site. While densities of natural seedlings declined on all plots between the first and second year, the attrition rate was lower on cut plots. At Harris Creek in the fall of 1987, there were 3730 natural red oak seedlings/ha on the cut-herbicided plots and 869/ha on control plots. At Warner Creek, there were 1470 natural

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red oak seedlings/ha on cut-herbicided plots and 430/ha on control plots.

Growth and Vigor of Oak Seedlings

Shoot growth of planted seedlings in 1986 averaged 11.5 cm at Harris Creek and 8.9 cm at Warner Creek. Shoot growth in the first year was not affected by treatment, perhaps because of the effect of uniform nursery conditions on planting stock in the preceding year. In the second year, shoot growth on cut plots at Harris Creek was significantly greater than growth on uncut plots (9.0 vs. 4.7 cm, $P < 0.01$). Planted seedlings on cut plots at Warner Creek also grew more than those on uncut plots (5.5 vs. 3.8 cm), but the difference was not statistically significant ($P = 0.16$). Height growth of planted seedlings was not consistently affected by herbicide treatment of low vegetation at either site. The total heights of natural red oak seedlings, which averaged 15.6 cm at Harris Creek and 14.3 cm at Warner Creek in 1987, were not affected by either cutting or herbicide treatment of low vegetation.

Cutting generally had a beneficial effect on seedling vigor as measured by number of first-order branches or number of leaves per seedling. Planted seedlings on cut plots in 1987 had 53% and 70% more first-order branches than those on uncut plots at Harris Creek and Warner Creek, respectively ($P \leq 0.02$). At Warner Creek, where low vegetation was not very dense, cutting also had a significant effect on the average number of leaves for natural seedlings (5.5 on cut, 3.5 on uncut, $P = 0.03$). At Harris Creek, cutting did not affect number of leaves on natural seedlings, probably because they were mostly overtopped by the dense herbaceous vegetation. Numbers of branches or leaves were not affected by herbicide treatment for either natural or planted seedlings on either site.

## CONCLUSIONS

Overstory reduction to 70% crown cover and removal of suppressed understory trees had significant positive effects on the survival, growth, and vigor of planted oak seedlings. As was found by Johnson (1984), height growth of planted seedlings under the shelterwood is modest, but development of the root system and adjustment to the site is probably more important at this stage than increase in height.

The least intensive treatments investigated in this study were underplanting in an undisturbed stand, and foliar herbicide treatment of ground vegetation in uncut stands. It may be too early to determine if underplanting by itself is a viable option. But after 2 years, seedlings under a full canopy do not appear to be vigorous, and 15-27% have already died. Herbicide treatment of the low vegetation by itself or in combination with cutting had little effect on growth or vigor of seedlings. Thus, under the present circumstances, special efforts to control vegetation < 1.0 m high do not appear to be warranted. However, it is possible that herbicide treatment of spring flora might have been more beneficial, and the reduction of small tree saplings on herbicided plots may have long-term benefits after the shelterwood overstory is removed.

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# COMPARATIVE GROWTH AND PHYSIOLOGY OF STEM-PRUNED AND UNPRUNED NORTHERN RED OAK[1]

ERIC L. KRUGER AND PETER B. REICH[2]

## INTRODUCTION

Top kill and subsequent root collar sprouting are inevitable consequences of fire and other disturbances which may aid the re-establishment of oak in mesic hardwood stands. As part of an effort to explore the role of sprouting in the regeneration of northern red oak (Quercus rubra L.) on mesic sites, the response of young red oak to stem pruning was examined in field and greenhouse studies.

## METHODS

In the first of two studies, we compared the ecophysiology of stem-pruned and unpruned natural red oak regeneration on a clearcut in southwestern Wisconsin. The site was on a southeast-facing slope with a silt loam cap and a red oak site index of about 65. Thirty 0.5 to 1.5 m tall red oak were stem-pruned 2 cm above the root collar in the spring of 1987. Diel measurements of leaf gas exchange and water potential were then conducted on sprouts and unpruned seedlings during sunny days throughout the growing season. The specific mass ($g/cm^2$), nutrient status and water relations parameters (i.e., osmotic potential at full turgor) of both leaf types were also monitored over the course of the study.

In the second study, we took a comprehensive look at the response of young red oak to stem pruning by comparing the growth and physiology of stem-pruned and unpruned 1-0 bare root planting stock in a greenhouse. Seedlings were planted in 8 liter pots of silt loam. One half of them were immediately stem-pruned 2 cm above the root collar. Seedling dry mass increment and allocation pattern, leaf gas exchange and leaf water relations were then measured over a 6 month period.

## RESULTS

### Field Study

Leaves of sprouts and unpruned seedlings had similar seasonal patterns of specific mass, nutrient status and water relations characteristics. Daily averages for net photosynthetic rate (A) and stomatal conductance ($g_s$) were 30% higher for sprout leaves than for leaves of unpruned seedlings. This was due partly to higher sprout leaf daily A and $g_s$ maximums and mostly to differences between leaf types in diel A and $g_s$ patterns. Typically, unpruned seedling A and $g_s$ declined substantially over a photoperiod following a morning maximum, while sprout leaves maintained near-maximum A and $g_s$ throughout the day. Diel leaf water potential patterns were similar, but sprout leaves were less water-stressed than unpruned seedling leaves at a given rate of transpiration, indicating greater water availability to the former. Coincident with this was the fact that sprouts had 25% less leaf area than unpruned seedlings at the end of the study.

### Greenhouse Study

Generally, stem pruning caused no change in seedling growth, morphology or physiology. However, growth of new stems (both dry mass and length increment) was 50% greater for sprouts than for unpruned seedlings. This shift of dry mass from original stem secondary growth to new stem length represented less than 3% of total seedling dry mass, but it allowed sprouts to recover about 75% of unpruned total stem length by the end of the study.

## DISCUSSION

Spring or dormant season stem pruning appears to do little harm to the photosynthetic capability of young northern red oak. Although sprouts had less leaf area than unpruned natural regeneration in the field, average sprout leaf photosynthetic rate was much higher. Thus sprouts compensated at least in part for the lack of leaf area. The enhanced sprout leaf function might have been due to increased water availability or to some other factor related to an increase in sprout root to shoot ratio, which would have occurred if sprout and unpruned seedling root systems were of similar size.

Greenhouse sprouts produced similar leaf areas and grew equally to unpruned seedlings. In fact, sprouts recovered much of the stem length lost to pruning via the allocation of dry mass to new stem extension in lieu of original stem secondary growth. Leaf function did not differ between types, possibly owing to a lack of difference between sprouts and unpruned seedlings in root to shoot ratio.

Further studies will assess the relative response of several mesic hardwoods to top kill in order to determine whether this aspect of disturbance confers any advantage to northern red oak regeneration on mesic sites.

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Proceedings of the seventh central hardwood forest conference, March 5-8, 1989 at Carbondale, Illinois. Includes 48 manuscripts dealing with silviculture, biology, management, protection, regeneration, utilization, structure, hydrology, and research policy in the central hardwood forest.

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KEY WORDS: Rhizosphere relations, oak decline, thinning, natural regeneration.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION

United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

General Technical
Report **NC-133**

# Impact and Control of *Septoria musiva* on Hybrid Poplars

Michael E. Ostry, Louis F. Wilson, and Harold S. McNabb, Jr.

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# Impact and Control of *Septoria Musiva* on Hybrid Poplars


**Michael E. Ostry, Louis F. Wilson and Harold S. McNabb, Jr.**


*Septoria musiva* Peck and its ascogenous state, *Mycosphaerella populorum* Thompson, have extensively damaged hybrid *Populus* planted in the north central United States. Many of the clones recently planted for fiber and energy production in intensively managed plantations are highly susceptible to *S. musiva*, resulting in premature defoliation and multiple branch and stem cankers (Ostry and McNabb 1985). Biomass yields from highly susceptible clones are limited, and coppice reproduction is reduced by these diseases (McNabb *et al.* 1982, Moore *et al.* 1982).

From 1975 to 1980, nearly 1,200 ha of hybrid poplars were planted in central lower Michigan for fiber packaging material. The goal was to obtain 25-cm-d.b.h. trees on a 15-year rotation. Many of these plantations were established before *Septoria*-resistant clones were identified. By the early 1980's most of the trees of susceptible clones were affected by the foliar and canker diseases caused by *S. musiva*. A study was undertaken to: (1) assess the impact of *Septoria* on the affected plantations and to determine if the trees could be carried to full rotation, (2) determine if disease severity of susceptible clones could be minimized by planting mixtures of clones with differing resistance to *S. musiva*, and (3) determine if pruning and sanitation could reduce disease severity within plantations.

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## MATERIALS AND METHODS

### Disease Progression and Impact

This study was conducted in a mixed-hybrid *Populus* plantation in Mason County, Michigan. The plantation was established in the spring of 1979 with unrooted hardwood cuttings of a random mixture of clones spaced 2.4 m apart within rows and 3.0 m between rows. In March 1984 five plots were randomly established within this plantation. Each plot consisted of three rows of 10 trees each. Because some of the trees had multiple stems, 180 stems were premanently marked within the plantation. Tree height and diameter were measured at the time of plot establishment and again in 1985. Each fall of 1984 to 1986 the incidence and severity of Septoria canker were recorded by using the categories: healthy, no cankers; branch cankers only; 1-2 stem cankers; 3+ stem cankers; top broken at canker; and dead, killed by *Septoria*.

### Clone Deployment

During the spring of 1980, a 2.9-ha research plot was established within each of three plantations of hybrid poplars, two in Manistee County and one in Mason County, Michigan. The three plantations ranged in size from 8 to 28 ha. Each plot was delimited from the remainder of the plantation and consisted of three rectangular blocks planted with cuttings of 32 hybrid poplar clones (table 1). To help identify each clone, the ends of the cuttings were sprayed with latex paint in various color combinations. Approximately 128 unrooted hardwood cuttings of each clone were mixed together and randomly planted in each block, spaced 2.4 m apart within rows and 3.0 m between rows (approximately 1,359 cuttings/ha). After planting, the identity of all cuttings was mapped for future reference.

Table 1.—*Disease susceptibility of* Populus *clones planted in random mixtures in Michigan, 1980-1986*[1]

| Clone | Parentage | Disease susceptibility[1] |
|---|---|---|
| NE 253 | *P. deltoides* var. *angulata* X *P. trichocarpa* | S |
| NE 235 | *P. deltoides* X *P. nigra* Incrassata | S |
| NE 386 | *P. candicans* X (*P.* X *berolinensis*) | S |
| NE 387 | | S |
| NE 388 | *P. maximowiczii* X *P. trichocarpa* | S |
| NE 375 | *P. deltoides* var. *angulata* X *P. nigra* var. *plantierensis* | - |
| NE 373 | *P. deltoides* var. *angulata* X *P. trichocarpa* | S,M |
| NE 252 | | S |
| NE 300 | *P. nigra* var. *betulifolia* X *P. trichocarpa* | S |
| NE 17 | *P. nigra* var. *charkowiensis* X *P. nigra* var. *caudina* | S |
| NE 19 | | - |
| NE 20 | | S |
| NE 205 | | S,M |
| NE 206 | *P. deltoides* X *P. trichocarpa* | S,R |
| NE 359 | | S |
| NE 207 | | S,M |
| NE 351 | *P. deltoides* X *P. nigra* var. *caudina* | S |
| NE 353 | | - |
| NE 366 | | S |
| NE 367 | | M |
| NE 264 | *P. deltoides* var. *angulata* X *P. nigra* Volga | M |
| NE 238 | *P. deltoides* X *P. nigra* Volga | - |
| NE 278 | *P. nigra* X (*P.* X *euramericana* Eugenii) | - |
| NE 51 | *P. maximowiczii* X *P. nigra* var. *plantierensis* | - |
| Wisc 5 | *P.* X *euramericana* Wisconsin #5 | - |
| I45-51 | *P.* X *euramericana* I45-51 | M |
| Raverdeau | *P.* X *euramericana* Robusta Raverdeau | - |
| DN 34 | *P.* X *euramericana* Eugenii | - |
| DN 30 | *P.* X *euramericana* Canada Blanc | - |
| DN 21 | *P.* X *euramericana* Jacometti | - |
| DN 28 | *P.* X *euramericana* Ostia | - |
| DN 17 | *P.* X *euramericana* Robusta | - |

[1] S = *Septoria* canker, M = *Marssonina* leaf blight, and R = *Melampsora* leaf rust. Clones were either prematurely defoliated or subject to stem cankers in all three plantations to such a degree that these clones should not be planted where these pathogens are known to be a problem. Clones with no rating were either disease-free or only slightly affected during the study period in Michigan. However, several of these clones are known to be susceptible to one or more diseases in other areas of the north central United States.

During each growing season from 1980 to 1986, the incidence and severity of insects and diseases affecting trees in the plots were assessed monthly by examining every tree in one of the blocks in each plantation. Insects and diseases affecting tree foliage were rated on the scale: Slight = 1 to 33 percent of the foliage affected, Moderate = 34 to 66 percent, Severe = 67 to 100 percent. Insects and diseases affecting tree branches and stems were rated as follows: Slight = affecting a few branches only, Moderate = affecting many branches and/or stems, Severe = affecting stems so that tree breakage was occurring. Additionally, tree survival was recorded in 1983.

### Pruning/Sanitation

In May 1982, a pruning/sanitation study was established in a 3-year-old mixed-hybrid poplar plantation in Mason County, Michigan. Six plots of 100 trees each were randomly located, and all chosen trees were marked with numbered metal tags. Tree height, diameter, and incidence of Septoria leafspot and canker were recorded. Trees on two of the plots were pruned to remove the lower one-third of the crown. Septoria cankers found after pruning were not removed. On another two plots, all trees with stem cankers were removed, and the remaining trees were pruned as on the previous plots. The final two plots served as controls and received no treatment. Spore traps (Ostry and Nicholls 1982) were placed in each plot and monitored weekly to determine the presence of inoculum within the plantation. Canker incidence was recorded each year from 1982 to 1984. Canker incidence, tree survival, and diameters were recorded in the fall of 1986. The incidence of poplar-willow-borer *Cryptorhynchus lapathi* (L.) attacks was recorded throughout the study period.

## RESULTS AND DISCUSSION

### Disease Progression and Impact

Five years after planting, 86 percent of the trees had Septoria cankers (table 2). By August of 1984, five months after the plots were established, 33 percent of the trees had broken tops; and by September of 1986, seven years after planting, 69 percent of the trees had broken tops. Although few trees died, many of the trees with broken tops lost as much as one-third of their total height growth by the end of the study. The mean tree diameter and height in 1984 was 7.7 cm and 7.4 m respectively. The mean tree diameter in 1986 was 10.0 cm, and most infected trees with broken tops had not formed new leaders.

Table 2.—*Incidence of* Septoria-*infected trees and tree mortality in a Michigan plantation of hybrid poplars, 1984-1986*[1]

| | Percentage of trees affected on:[2] | | | |
|---|---|---|---|---|
| Tree condition | 3-84 | 8-84 | 9-85 | 9-86 |
| Healthy, no cankers | 14 | 9 | 8 | 4 |
| Branch cankers only | 4 | 4 | 3 | 2 |
| 1-2 bole cankers | 16 | 13 | 12 | 7 |
| 3+ bole cankers | 57 | 40 | 32 | 17 |
| Top broken at canker | 9 | 33 | 44 | 69 |
| Dead, killed by *Septoria* | 0 | 1 | 1 | 1 |

[1] Planted 1979.
[2] N = 180.

The incidence and severity of *Septoria* differed among clones. Because the plantation was just reaching the midpoint in its planned 15-year rotation at the end of this study, it was doubtful that any of the highly susceptible trees will survive to the projected harvest age. Only scattered groups of resistant trees will remain, making this plantation uneconomical to manage.

### Clone Deployment

Survival of individual clones after 3 years ranged from 38 to 93 percent, averaging 69, 71, and 66 percent on the three sites. The incidence and severity of disease and insect attacks on specific clones were similar at all three sites and were similar to previous findings (Moore et al. 1982, Ostry and McNabb 1985). Three major pathogens and one insect pest seriously affected many of the clones. *Septoria musiva* had by far the greatest impact on trees, causing premature defoliation and stem cankers that resulted in dead and broken tops (figs. 1 and 2). *Marssonina brunnea* (Ell. & Ev.) Magn. and *Melampsora medusae* Thum. also caused premature defoliation of several highly susceptible clones. The major damaging insect pest was the poplar-and-willow borer. This borer was often present on trees also affected by Septoria canker, but no clonal preferences were discernible because of the low incidence of borer attacks.

Figure 1.–*Partially defoliated* Populus *clone susceptible to* Septoria musiva *(left) compared with resistant clone.*

Within each planting, all trees of the same clone were similarly affected by the same pathogen. Often a clone could be identified on the basis of the severity of the particular disease to which it was susceptible. The presence of resistant trees surrounding highly susceptible trees did not appear to prevent disease or minimize disease severity. The clones most severely affected by the various pathogens are listed in table 1. These clones should not be planted where these pathogens are known to be a problem. Most of the clones severely affected by *Septoria* were declining, leaving large openings in the plantations. From a management standpoint, the best strategy may be to plant trees of several resistant clones in monoclonal blocks in a mosaic pattern. These blocks could then be treated individually if a disease outbreak necessitated chemical control or early harvest.

**Pruning/Sanitation**

Pruning was ineffective in reducing the incidence of Septoria canker. New branch and stem cankers were common above the pruned portions of trees. The number of trees with cankers per plot ranged from 7 to 16 before treatment in 1982 and from 10 to 18 after treatment in 1986. Most stem cankers either killed trees or killed the tops, predisposing affected trees to wind breakage. Overwintering inoculum in the leaf litter (Ostry 1987) evidently was disseminated into the upper crowns of the pruned trees. Previous work also has shown that sanitation is not an effective control strategy for *Septoria* if abundant inoculum is present within adjacent trees (Ostry 1987). Spore trap counts

Figure 2.–*Multiple stem cankers caused by* Septoria musiva *on a highly susceptible* Populus *clone.*

revealed similar numbers of conidia of *Septoria* and ascospores of *Mycosphaerella* in all plots throughout the growing season.

Tree mortality was 4 percent within all the study plots. Thirteen percent of the remaining trees had Septoria cankers; 8 percent of the affected trees had dead or broken tops. Differences in clonal susceptibility were evident; most cankers were associated with only a few clones. There was no increase in the incidence of poplar-willow-borer attacks from 1982 to 1986, and there seemed to be no clonal preferences.

**SUMMARY**

*Septoria musiva* caused extensive damage to highly susceptible hybrid poplars in many production plantings in central lower Michigan. Stem breakage was common within 5 years after plantation establishment. Severity differed by clone, not

site. Pruning the lower branches to reduce infection sites and removing *Septoria*-infected trees failed to reduce disease incidence and severity within plantations. Planting resistant and susceptible clones in random mixtures did not protect the susceptible trees from infection. Inoculum produced on leaves of susceptible trees was dispersed throughout plantations, causing an unacceptable incidence of disease. Planting blocks of resistant clones in a mosaic pattern will allow blocks of severely affected clones to be harvested early, if necessary, while the remainder of the plantation is managed as originally planned. Planting only resistant clones in monoclonal blocks is recommended to minimize the serious risk of this pathogen.

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Describes the impact of Septoria canker on hybrid poplars in production plantations and the results of cultural control studies.

KEY WORDS: *Populus*, canker, intensive culture.

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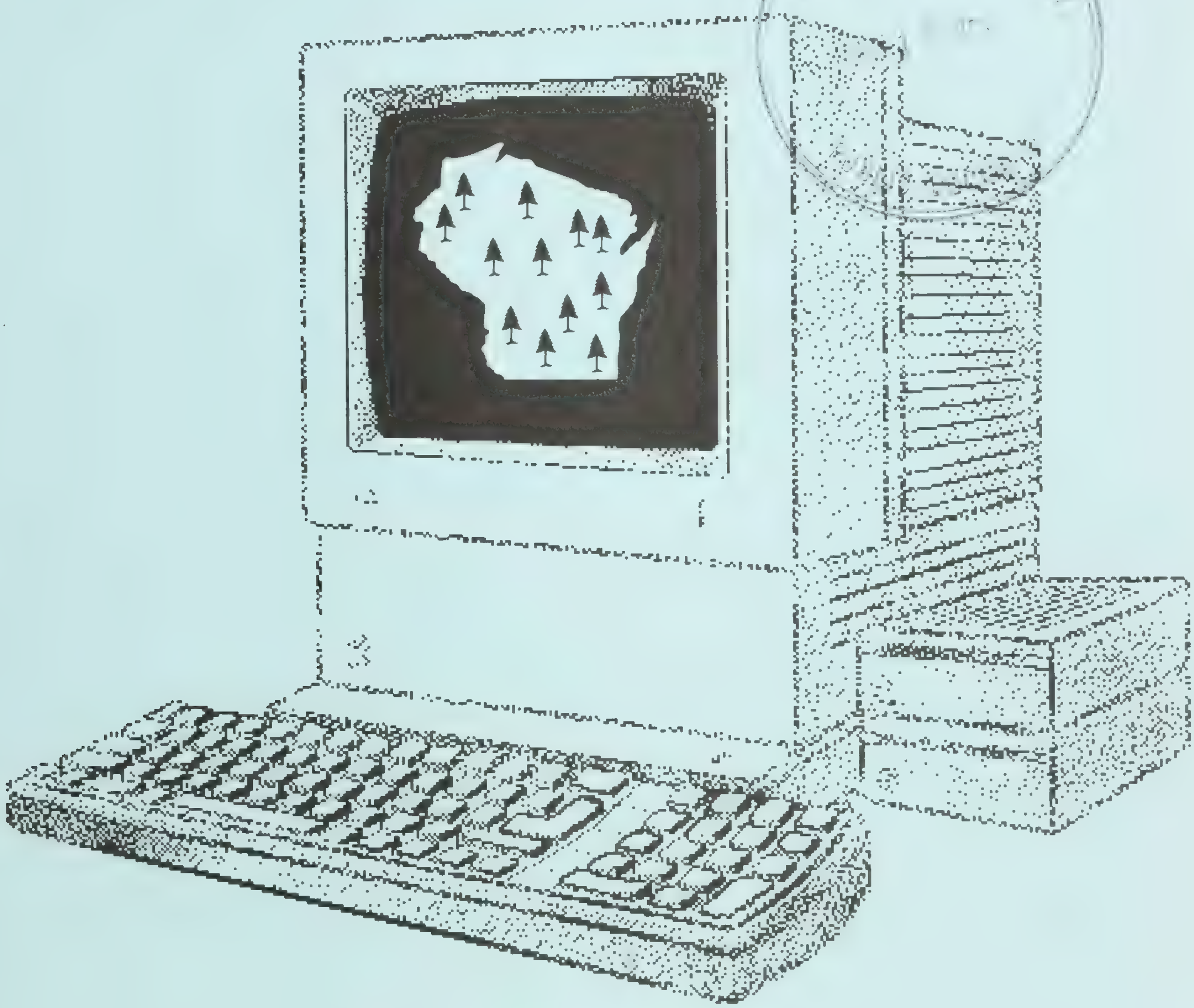
General Technical Report **NC-134**

# Operability and Location of Wisconsin's Timber Resource

Jerold T. Hahn and Mark H. Hansen





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from the stand. Public and private forestry representatives identified these as the most important factors in determining operability. The same components were used by Spencer *et al*. (1986) in Minnesota and Hansen and Hahn (1987) in Michigan.

Operability classifications I, II, or III (good, medium, or poor) were defined for each component (table 1). The ranges of these classifications were selected after extensive review by professionals from both public and private forest management and timber acquisition in the Lake States region. These reviewers suggested changes in some of the range limits between Minnesota and Michigan. We note these changes in the footnotes of table 1. Ranges for Michigan and Wisconsin are identical and reflect the standards held by timber industry professionals for good, medium, or poor operability stands in both States.

The overall operability classification of any area was determined by a computer scan of the plot records and is based on the poorest operability component. In order for an inventory plot to be rated operability class I (good), all of the values for the seven components on the plot had to be class I. A plot was rated class II (medium) if any component was rated class II and the other six were at least class I. A plot was rated operability class III (poor) if any of the component values were class III. For example, if the values for six components on a plot were class I and the value for the remaining component was class III, the plot was considered operability class III. All sapling-seedling and nonstocked plots were considered inoperable (class IV); we believe that most of this land would not be harvested in the near future and that including it in the study would dilute the findings.

Table 1.—*Operability component values for each operability class*

| Operability component/ limiting factor | Operability class I (good) | II (medium) | III (poor) |
|---|---|---|---|
| Stand area (in acres) | More than 60 | 10-60 | Less than 10 |
| Growing-stock volume per acre (includes cubic foot volume of sawtimber-sized material) (in cubic feet)[1] | More than 1,000 | 400-1,000 | Less than 400 |
| Sawtimber volume per acre (in board feet, International 1/4-inch rule)[2] | More than 2,500 | 700-2,500 | Less than 700 |
| Percent of all live trees that are cull (in percent | Less than 20 | 20-50 | More than 50 |
| Average diameter at breast height (d.b.h.) of growing-stock trees (in inches)[3] | More than 9 | 6-9 | Less than 6 |
| Average merchantable height of growing-stock trees (in feet) | More than 28 | 16-28 | Less than 16 |
| Distance to a maintained road (in miles) | Less than 1/4 | 1/4 - 3/4 | More than 3/4 |

[1]Threshold values for growing-stock volume per acre used in the Minnesota study (Spencer *et al.* 1986) were: more than 800, 300 to 800, and less than 300 cubic feet per acre.

[2]Threshold values for sawtimber volume per acre used in the Minnesota study (Spencer *et al.* 1986) were: more than 3,000, 1,100 - 2,000, and less than 1,100 board feet per acre.

[3]Threshold values for average d.b.h. of growing-stock trees used in the Minnesota study (Spencer *et al.* 1986) were: more than 10, 6-10, and less than 6 inches.

The components that prevent a plot from being classed higher, or limiting factors, are useful to those that find our definitions of the operability classes too restrictive. Using the information presented in the Appendix, people can develop their own criteria for determining operability. For example, you may wish to rank the importance of limiting factors, allow more than one factor to deviate from the majority, or eliminate a factor entirely. Additional volumes or areas may be rated class I or II if some limiting components are disregarded.

With the assistance of the Wisconsin DNR, we identified 14 major wood-using centers in Wisconsin (fig. 1): Cornell-Stanley, Durand, Green Bay, Hayward, Kaukauna, Niagara-Peshtigo, Onalaska, Park Falls, Rice Lake-Spooner, Shawano, Superior, Tomahawk, Wausau, and Wisconsin Rapids. Using the straight-line distance from the plots to these centers (computed from the Universal Transverse Mercator coordinates of the center and the plots), we computed area of forest land (table 13) and growing-stock volume (table 14) by operability class.

## RESULTS

### Area

About 6.1 million acres (41 percent) of timberland in Wisconsin are rated operability class II — medium. This class accounts for more of Wisconsin's timberland than any of the other classes (table 7). Another 4.5 million acres (31 percent) are rated class III — poor; and 260,900 acres (less than 2 percent) are rated class I — good. Class IV forest, sapling and seedling stands and nonstocked areas, total 3.9 million acres (26 percent). Only 8 of the 14 forest types identified in Wisconsin have area in operability class I (table 7). Although the criteria we used may be restrictive, it is possible to relax them as described below. We would appreciate comments on the use of the criteria in this study.

*Adjustment by Limiting Factors*

By removing some limiting factors, a user can shift some forest area into the good operability class (class I). For


Figure 1.--*Location of major wood-using centers in Wisconsin*

example, by using tables 7 and 8 and waiving the stand area component the 260,900 acres originally rated operability class I can be increased to 673,900 acres (260,900 + 413,000 acres). The total area in class I becomes 569,400 acres (260,900 + 308,500 acres) by removing the distance to road component. Waiving both components, the new class I area becomes 1,324,400 acres (260,900 + 413,000 + 308,500 + 342,000 acres). Although the new area is 5 times larger than the original area, it still represents only 12 percent of the State's total for classes I-III.

*Ownership*

The portion of timberland in each operability class differs among ownership classes (table 3). Four ownership groups — Indian, National Forest, farmer, and forest industry — together own more than 40 percent of the timberland in Wisconsin and the highest percentages of timberland in operability classes I and II. The Indian ownership group with 10 percent of its land in operability class I has by far the greatest amount in this class. This is probably due to the ease of access and high volumes per acre in Menominee County, where all of the land is owned by Indians. Timberland in the Indian, National Forest, and forest industry ownership groups probably is managed more intensively than private timberland and may be predisposed to higher operability ratings. The farmer-owned land tends to be more accessible by road in Wisconsin and is probably in the higher operability classes for this reason.

*Distance From Wood-using Center*

Nearly 424,000 acres of operable timberland are within a 20-mile radius of Hayward, Wisconsin (table 13). Hayward had the greatest concentration of operable timberland of any major wood-using center in the State. Park Falls, Wisconsin, had 391,000 acres and Tomahawk had 347,000 acres within 20 miles. If the timbershed is extended to a radius of 50 miles, Hayward is still first with 2,352,000 acres, followed by Park Falls (2,301,000) and Tomahawk (1,965,000).

If we consider distance by operability class, a different picture emerges. Shawano, Wisconsin, leads with 19,800 acres in operability class I timberland within 20 miles of town. However, because class I area is so small, it makes more sense to expand the discussion to operability classes I and II. When this is done, Park Falls (235,000 acres), Hayward (232,000), and Tomahawk (183,000) again lead the list.

**Volume**

We also classed growing-stock volume on timberland in Wisconsin by operability class. Because the same kind of tables were generated for volume as for area, we present only the highlights.

Table 2.—*Area of operable timberland by ownership class and operability class, Wisconsin, 1983*

| Ownership class | All classes | Operability class I | II | III |
|---|---|---|---|---|
| | *Thousand acres* | | *- - - - -Percent- - - - -* | |
| Indian | 320.8 | 10 | 53 | 37 |
| National Forest | 1,015.5 | 3 | 61 | 36 |
| Farmer | 2,716.1 | 2 | 61 | 37 |
| Forest industry | 800.1 | 4 | 58 | 38 |
| State | 372.1 | 2 | 58 | 40 |
| Misc. private | 4,055.3 | 2 | 56 | 42 |
| County and municipal | 1,489.4 | 1 | 45 | 54 |
| Other federal | 108.8 | 0 | 50 | 50 |
| All owners | 10,878.1 | 1 | 45 | 54 |

Wisconsin's 1983 growing-stock inventory of 14.3 billion cubic feet is broken down into operability classes as follows:

| Operability class | Growing-stock volume (Million cubic feet) | (Percent) |
|---|---|---|
| I | 499 | 3 |
| II | 8,852 | 62 |
| III | 4,962 | 35 |
| All classes | 14,313 | 100 |

The maple-birch type, which represents 33 percent of the combined volumes in classes I through III, includes 50 percent of the operability class I volume (table 15). These figures reflect the bias of the components towards larger, older trees.

*Adjustment by Limiting Factors*

Users can adjust volumes in the same way they adjusted area. Waiving the same two operability components as in the area discussion (stand area and distance to road) changes the volume in operability class I from 499 to 2,503 million cubic feet (tables 15 and 16). The volume in operability class II shifts from 8,851 to 9,524 million cubic feet (tables 15 and 17). Percentages in each class then become:

| Operability class | Volume (Percent) |
|---|---|
| I | 17 |
| II | 67 |
| III | 16 |
| All classes | 100 |

*Volume Per Acre*

As expected, higher volumes per acre are associated with the better operability classes (tables 3 and 4). All of the class I land, 73 percent of class II land, and 49 percent of class III land have more than 1,000 cubic feet of growing-stock volume per acre.

Table 3.—*Percent of operable timberland by growing-stock volume and operability class, Wisconsin, 1983*

(In percent)

| Growing-stock volume/acre (cu ft/acre) | Operability class I | II | III |
|---|---|---|---|
| More than 1,000 | 100 | 73 | 49 |
| From 400 to 1,000 | — | 27 | 39 |
| Less than 400 | — | — | 12 |
| Total | 100 | 100 | 100 |

Table 4.—*Average growing-stock volume per acre on operable timberland by volume and operability class, Wisconsin, 1983*

(In cubic feet/acre)

| Volume/acre class (cu ft/acre) | Average all classes | Operability class I | II | III |
|---|---|---|---|---|
| More than 1,000 | 1,683 | 1,912 | 1,702 | 1,618 |
| From 400 to 1,000 | 742 | — | 770 | 716 |
| Less than 400 | 268 | — | — | 268 |

*Ownership*

All owners except county, municipal, and other federal have more than 65 percent of their growing-stock volume in operability classes I and II (table 5). The Indian and National Forest owners have 70 percent of their growing-stock volume in operability classes I and II; Indian owners have 13 percent of their volume in operability class I. As is the case with area, this large volume of Indian ownership in operability class I is probably due to the high volumes per acre and excellent quality (indicated by a low percent of cull trees and high average d.b.h.) of the timber in Menominee County.

Table 5.—*Growing-stock volume on operable timberland by ownership class and operability class, Wisconsin, 1983*

| Ownership class | All classes | Operability class I | II | III |
|---|---|---|---|---|
| | *Thousand cubic feet* | | *Percent* | |
| Indian | 619,159 | 13 | 57 | 30 |
| National Forest | 1,496,624 | 4 | 66 | 30 |
| Farmer | 3,385,531 | 2 | 67 | 31 |
| Forest industry | 1,145,432 | 5 | 62 | 33 |
| State | 493,363 | 4 | 62 | 34 |
| Misc. private | 5,175,062 | 3 | 63 | 34 |
| County and municipal | 1,873,068 | 1 | 51 | 48 |
| Other federal | 124,864 | — | 56 | 44 |
| All owners | 14,313,103 | 3 | 62 | 35 |

*Distance From Wood-using Center*

Park Falls is within 20 miles of 361 million cubic feet of operability class I and II growing stock — more than any other wood-using center in the State. Hayward and Shawano follow with 352 and 338 million cubic feet, respectively (table 21). If the radius is extended to 50 miles, the cities are in the same order.

### Summary

The tables we provide separate timberland area and growing-stock volume into operability classes by forest type, volume per acre class, stand-age class, ownership class, and distance from wood-using center. The tables also permit the user to discount up to three operability components and determine operability class based on the remaining selected components.

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## APPENDIX

Principal Tree Species Groups in Wisconsin[2]

**Softwoods**

Eastern white pine ..................... *Pinus strobus*
Red pine ..................... *Pinus resinosa*
Jack pine ..................... *Pinus banksiana*
White spruce ..................... *Picea glauca*
Black spruce ..................... *Picea mariana*
Balsam fir ..................... *Abies balsamea*
Eastern hemlock ..................... *Tsuga canadensis*
Tamarack ..................... *Larix laricina*
Northern white-cedar ..................... *Thuja occidentalis*
Other softwoods
  Eastern redcedar ..................... *Juniperus virginiana*
  Norway spruce ..................... *Picea abies*
  Engelmann spruce ..................... *Picea engelmannii*
  Austrian pine ..................... *Pinus nigra*
  Scotch pine ..................... *Pinus sylvestris*

**Hardwoods**

White oak
  White oak ..................... *Quercus alba*
  Swamp white oak ..................... *Quercus bicolor*
  Bur oak ..................... *Quercus macrocarpa*
  Chinkapin oak ..................... *Quercus muehlenbergii*
  Chestnut oak ..................... *Quercus prinus*
Select red oak
  Northern red oak ..................... *Quercus rubra*

[2]*The common and scientific names are based on: Little, Elbert L. 1979. Checklist of native and naturalized trees of the United States. Agric. Handb. 541. Washington, DC: U.S. Department of Agriculture, Forest Service. 375 p.*

Other red oak
- Scarlet oak ..................................... *Quercus coccinea*
- Northern pin oak ..................... *Quercus ellipsoidalis*
- Pin oak ........................................... *Quercus palustris*
- Black oak ....................................... *Quercus velutina*

Hickory
- Bitternut hickory ............................. *Carya cordiformis*
- Pignut hickory ......................................... *Carya glabra*
- Shellbark hickory ................................ *Carya laciniosa*
- Shagbark hickory ...................................... *Carya ovata*
- Mockernut hickory ............................ *Carya tomentosa*

Yellow birch ................................. *Betula alleghaniensis*

Hard maple
- Sugar maple ....................................... *Acer saccharum*
- Black maple ............................................. *Acer nigrum*

Soft maple
- Red maple ................................................ *Acer rubrum*
- Silver maple .................................... *Acer saccharinum*

Beech .................................................. *Fagus grandifolia*

Ash
- White ash ..................................... *Fraxinus americana*
- Black ash ............................................. *Fraxinus nigra*
- Green ash ............................... *Fraxinus pennsylvanica*

Balsam poplar ................................ *Populus balsamifera*

Eastern cottonwood ............................. *Populus deltoides*

Aspen
- Bigtooth aspen ......................... *Populus grandidentata*
- Quaking aspen ............................ *Populus tremuloides*

Basswood ............................................... *Tilia americana*

Yellow-poplar ............................ *Liriodendron tulipifera*

Black walnut ............................................. *Juglans nigra*

Black cherry .......................................... *Prunus serotina*

Butternut ................................................. *Juglans cinerea*

Elm
- American elm ................................... *Ulmus americana*
- Slippery elm ............................................ *Ulmus rubra*
- Rock elm ............................................. *Ulmus thomasii*

Paper birch .......................................... *Betula papyrifera*

Other hardwoods
- Boxelder ................................................ *Acer negundo*
- Sweet birch ............................................... *Betula lenta*
- River birch .............................................. *Betula nigra*
- Black willow ............................................. *Salix nigra*
- Ohio buckeye ..................................... *Aesculus glabra*
- Flowering dogwood .............................. *Cornus florida*
- Honeylocust ................................ *Gleditsia triacanthos*
- Osage-orange .................................. *Maclura pomifera*
- Black tupelo ................................. *Nyssa sylvatica* var. *sylvatica*
- Sycamore .................................. *Platanus occidentalis*
- Black locust .............................. *Robinia pseudoacacia*
- Sassafras .......................................... *Sassafras albidum*
- Red mulberry .......................................... *Morus rubra*
- American chestnut ............................ *Castanea dentata*

**Metric Equivalents of Units Used in This Report**

1 acre = 4,046.86 square meters or 0.405 hectare.
1,000 acres = 405 hectares.
1 cubic foot = 0.0283 cubic meter.
1 mile = 1.61 kilometers.
1 foot = 30.48 centimeters or 0.3048 meter.
1 inch = 25.4 millimeters, 2.54 centimeters, or 0.0254 meter.

**Universal Transverse Mercator (UTM) Grid System**

The UTM Grid System is designed for world use between 80° south latitude and 84° north latitude. The globe is divided into narrow zones of 6° of longitude in width, numbered 1 through 60. Each zone is bounded on the east and west by a meridian of longitude and with a central meridian passing through the center of the grid zone. In the northern hemisphere the intersection of the central meridian and the equator is given a value of 0 meters for northing coordinate, and the numbers increase towards the north pole. Because values increase from west to east, this same point of intersection is given a value of 500,000 meters for easting coordinate to avoid negative numbers at the western edge of the zone. A grid system of two sets of parallel lines intersecting at right angles and forming a series of squares is established within each grid zone. On the U.S. Geological Survey 7.5 minute topographic maps, the grid interval or length of each side of these squares is 1,000 meters. Each grid intersection can be uniquely identified by its easting and northing and the zone number. The first of these coordinates represents the distance in meters east of the central meridian of the grid zone and the second coordinate represents the distance in meters north of the equator. Any point on a topographic map can be referenced by using these coordinates and by dividing the sides of the grid square into 10 or multiples of 10 parts. The point coordinates, then, are read to a greater number of digits than the grid coordinates. Such a system permits a point to be lo-cated to the nearest 10 meters. If the UTM coordinates of any two points are known, the distance between them can be easily computed, even if they are in different zones.

## DEFINITION OF TERMS

**Commercial forest land.**—(See timberland.)

**Commercial species.**—Tree species presently or prospectively suitable for industrial wood products. (Note: Excludes species of typically small size, poor form, or inferior quality such as hophornbeam and hawthorn.)

**County and municipal land.**—Land owned by counties and local public agencies or municipalities, or land leased to these governmental units for 50 years or more.

**Cull.**—Portions of a tree that are unusable for industrial wood products because of rot, poor form, or other defect.

**Farm.**—Any place from which $1,000 or more of agricultural products were produced and sold during the year.

**Farmer-owned land.**—Land owned by farm operators. (Note: Excludes land leased by farm operators from nonfarm owners, such as railroad companies and States.)

**Forest industry land.**—Land owned by companies or individuals operating primary wood-using plants.

**Forest land.**—Land at least 16.7 percent stocked by forest trees of any size, or formerly having had such tree cover, and not currently developed for nonforest use. (Note: Stocking is measured by comparing specified standards with basal area and/or number of trees, age or size, and spacing.) The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of timber must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, or other bodies of water or clearings in forest areas shall be classed as forest if less than 120 feet wide. Also see timberland.

**Forest trees.**—Woody plants having a well-developed stem and usually more than 12 feet tall at maturity.

**Forest type.**—A classification of forest land based upon the species forming a plurality of live-tree stocking. Major forest types in Wisconsin are:

*Jack pine.*—Forests in which jack pine comprises a plurality of the stocking. (Common associates include eastern white pine, red pine, aspen, birch, and maple.)

*Red pine.*—Forests in which red pine comprises a plurality of the stocking. (Common associates include eastern white pine, jack pine, aspen, birch, and maple.)

*White pine.*—Forests in which eastern white pine comprises a plurality of the stocking. (Common associates include red pine, jack pine, aspen, birch, and maple.)

*Balsam fir.*—Forests in which balsam fir and white spruce comprise a plurality of stocking with balsam fir the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

*White spruce.*—Forests in which white spruce and balsam fir comprise a plurality of the stocking with white spruce the most common. (Common associates include aspen, maple, birch, northern white-cedar, and tamarack.)

*Black spruce.*—Forests in which swamp conifers comprise a plurality of the stocking with black spruce the most common. (Common associates include tamarack and northern white-cedar.)

*Northern white-cedar.*—Forests in which swamp conifers comprise a plurality of the stocking with northern white-cedar the most common. (Common associates include tamarack and black spruce.)

*Tamarack.*—Forests in which swamp conifers comprise a plurality of the stocking with tamarack the most common. (Common associates include black spruce and northern white-cedar.)

*Oak-hickory.*—Forests in which northern red oak, white oak, bur oak, or hickories, singly or in combination, comprise a plurality of the stocking. Common associates include jack pine, beech, yellow-poplar, elm, and maple.)

*Elm-ash-soft maple.*—Forests in which lowland elm, ash, cottonwood, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include birches, spruce, and balsam fir.)

*Maple-birch.*—Forests in which sugar maple, basswood, yellow birch, upland American elm, and red maple, singly or in combination, comprise a plurality of the stocking. (Common associates include white pine, elm, hemlock, and basswood.)

*Aspen.*—Forests in which quaking aspen or bigtooth aspen, singly or in combination, comprise a plurality of the stocking. (Common associates include balsam poplar, balsam fir, and paper birch.)

*Paper birch.*—Forests in which paper birch comprises a plurality of the stocking. (Common associates include maple, aspen, and balsam fir.)

*Exotic.*—Forests in which species not native to Wisconsin comprise a plurality of the stocking. (Mostly scotch pine plantations.)

**Growing-stock trees.**—Live trees of commercial species, excluding rough and rotten trees.

**Growing-stock volume.**—Net volume in cubic feet of growing-stock trees 5 inches d.b.h. and over, from a 1-foot stump to a minimum 4 inch top diameter outside bark of the central stem or to the point where the central stem breaks into limbs. Cubic feet can be converted to

standard cords by dividing by 79. One stan-dard cord is 128 cubic feet of stacked wood, including bark and air.

**Hardwoods.**—Dicotyledonous trees, usually broad-leaved and deciduous.

**Indian land.**—All land held in trust by the United States for individual Indians or tribes, or all land titles held by individual Indians or tribes, subject to Federal restrictions against alienation.

**Live trees.**—Growing-stock, rough, and rotten trees 1 inch d.b.h. and larger.

**Maintained road.**—Any road, hard-topped or other surface, that is plowed or graded at least once a year. Includes rights-of-way that are cut or treated to limit herbaceous growth.

**Merchantable.**—Refers to the bole section of poletimber or sawtimber trees.

**Miscellaneous federal land.**—Federal land other than National Forest and land administered by the Bureau of Land Management.

**Miscellaneous private land.**—Privately owned land other than forest-industry and farmer-owned land.

**National forest land.**—Federal land that has been legally designated as National Forest or purchase units, and other land administered by the USDA Forest Service.

**Net volume.**—Gross volume less deductions for rot, sweep, or other defect affecting use for timber products.

**Noncommercial species.**—Tree species of typically small size, poor form, or inferior quality that normally do not develop into trees suitable for industrial wood products.

**Nonstocked land.**—Timberland less than 16.7 percent stocked with growing-stock trees.

**Poletimber stands.**—See stand-size class.

**Poletimber trees.**—Growing-stock trees of commercial species at least 5 inches d.b.h. but smaller than sawtimber size.

**Saplings.**—Live trees 1 to 5 inches d.b.h.

**Sapling-seedling stands.**—(See stand-size class.)

**Saw log.**—A log meeting minimum standards of diameter, length, and defect, including logs at least 8 feet long, sound and straight and with a minimum diameter outside bark (d.o.b.) for softwoods of 7 inches (9 inches for hardwoods) or other combinations of size and defect specified by regional standards.

**Saw log portion.**—That part of the bole of sawtimber trees between the stump and the saw log top.

**Saw log top.**—The point on the bole of sawtimber trees above which a saw log cannot be produced. The minimum saw log top is 7 inches d.o.b. for softwoods and 9 inches d.o.b. for hardwoods.

**Sawtimber stands.**—(See stand-size class.)

**Sawtimber trees.**—Growing-stock trees of commercial species containing at least a 12-foot saw log or two noncontiguous saw logs 8 feet or longer, and meeting regional specifications for freedom from defect. Softwoods must be at least 9 inches d.b.h. Hardwoods must be at least 11 inches d.b.h.

**Sawtimber volume.**—Net volume of the saw log portion of live sawtimber in board feet, International 1/4 -inch rule, from stump to a minimum 7 inches top diameter outside bark (d.o.b.) for softwoods and a minimum 9 inches top d.o.b. for hardwoods.

**Seedlings.**—Live trees less than 1 inch d.b.h. that are expected to survive. Only softwood seedlings more than 6 inches tall and hardwood seedlings more than 1 foot tall are counted.

**Softwoods.**—Coniferous trees, usually evergreen, having needles or scale-like leaves.

**Stand.**—A growth of trees on a minimum of 1 acre of forest land that is stocked by forest trees of any size.

**Stand-age class.**—Age of the main stand. Main stand refers to trees of the dominant forest type and stand-size class.

**Stand-size class.**—A classification of forest land based on the size class of growing-stock trees on the area; that is, sawtimber, poletimber, or seedlings and saplings.

a. *Sawtimber stands.*—Stands at least 16.7 percent stocked with growing-stock trees, with half or more of total stocking in sawtimber or poletimber trees, and with sawtimber stocking at least equal to poletimber stocking.

b. *Poletimber stands.*—Stands at least 16.7 percent stocked with growing-stock trees of which half or more of this stocking is in poletimber and/or sawtimber trees, and with poletimber stocking exceeding that of sawtimber.

c. *Sapling-seedling stands.*—Stands at least 16.7 percent stocked with growing-stock trees of which more than half of the stocking is saplings and/or seedlings.

d. *Nonstocked areas.*—Timberland on which stocking of growing-stock trees is less than 16.7 percent.

**State land.**—Land either owned by States or leased to them for 50 years or more.

**Timberland.**—(Formerly called commercial forest land.) Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization. (Note: Areas qualifying as timberland are capable of producing more than 20 cubic feet per acre of annual growth when managed. Currently inaccessible and inoperable areas are included except when the areas involved are small and unlikely to become suitable for producing industrial wood in the foreseeable future.)

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Table 21.—Growing-stock volume on timberland by distance from major wood-using center and operability class

Table 6.--Area of timberland by operability class component and forest type, Wisconsin, 1983

(In thousand acres)

| Operability class component | All types | Jack pine | Red pine | White pine | Balsam fir | White spruce | Black spruce | Northern white-cedar | Tamarack |
|---|---|---|---|---|---|---|---|---|---|
| | Forest type | | | | | | | | |
| Stand area (acres) | | | | | | | | | |
| More than 60 | 4,325.8 | 175.5 | 126.1 | 34.1 | 57.0 | 20.2 | 31.3 | 87.4 | 35.1 |
| 10-60 | 7,675.1 | 256.5 | 224.3 | 102.6 | 274.1 | 20.0 | 172.5 | 222.8 | 134.6 |
| Less than 10 | 2,758.5 | 114.5 | 127.8 | 88.9 | 88.3 | 21.2 | 69.2 | 60.5 | 53.0 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |
| Growing-stock volume (cubic feet/acre) | | | | | | | | | |
| More than 1,000 | 7,021.6 | 199.6 | 321.2 | 150.2 | 153.7 | 36.7 | 38.9 | 216.5 | 28.9 |
| 400-1,000 | 4,528.9 | 204.7 | 41.6 | 54.2 | 187.0 | 8.1 | 63.7 | 123.1 | 86.8 |
| Less than 400 | 3,208.9 | 142.2 | 115.4 | 21.2 | 78.7 | 16.6 | 170.4 | 31.1 | 107.0 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |
| Sawtimber volume (board feet/acre) | | | | | | | | | |
| More than 2,500 | 5,289.8 | 117.9 | 213.4 | 171.5 | 146.9 | 26.6 | 26.0 | 124.8 | 7.2 |
| 700-2,500 | 4,641.7 | 186.0 | 51.9 | 20.5 | 158.1 | 17.9 | 42.9 | 152.1 | 50.3 |
| Less than 700 | 4,827.9 | 242.6 | 212.9 | 33.6 | 114.4 | 16.9 | 204.1 | 93.8 | 165.2 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |
| Percent cull trees (percent) | | | | | | | | | |
| Less than 20 | 9,832.0 | 407.5 | 365.1 | 173.1 | 345.6 | 45.5 | 198.6 | 276.5 | 168.7 |
| 20-50 | 2,900.0 | 76.5 | 21.8 | 26.2 | 50.6 | 3.7 | 14.5 | 71.1 | 19.2 |
| More than 50 | 2,027.4 | 62.5 | 91.3 | 26.3 | 23.2 | 12.2 | 59.9 | 23.1 | 34.8 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |
| Average d.b.h. of growing-stock trees (inches) | | | | | | | | | |
| More than 9 | 5,126.2 | 73.5 | 93.5 | 110.6 | 75.7 | 7.1 | 10.0 | 51.1 | 17.2 |
| 6-9 | 8,129.4 | 362.5 | 251.2 | 102.8 | 312.8 | 41.2 | 156.0 | 284.2 | 142.2 |
| Less than 6 | 1,503.8 | 110.5 | 133.5 | 12.2 | 30.9 | 13.1 | 107.0 | 35.4 | 63.3 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |
| Average merchantable height of growing-stock trees (feet) | | | | | | | | | |
| More than 28 | 10,503.0 | 214.6 | 232.1 | 167.2 | 217.4 | 31.5 | 62.3 | 86.3 | 68.0 |
| 16-28 | 3,203.5 | 274.3 | 156.5 | 46.2 | 183.9 | 16.8 | 158.2 | 259.1 | 118.1 |
| Less than 16 | 1,052.9 | 57.6 | 89.6 | 12.2 | 18.1 | 13.1 | 52.5 | 25.3 | 36.6 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |
| Distance to road (miles) | | | | | | | | | |
| Less than 1/4 | 7,311.6 | 370.9 | 352.4 | 136.2 | 186.1 | 43.0 | 104.4 | 151.3 | 77.9 |
| 1/4-3/4 | 6,283.1 | 161.3 | 102.5 | 87.4 | 186.2 | 16.4 | 123.0 | 178.0 | 119.8 |
| More than 3/4 | 1,164.7 | 14.3 | 23.3 | 2.0 | 47.1 | 2.0 | 45.6 | 41.4 | 25.0 |
| All classes | 14,759.4 | 546.5 | 478.2 | 225.6 | 419.4 | 61.4 | 273.0 | 370.7 | 222.7 |

(Table 6 continued on next page)

(Table 6 continued)

| Operability class component | Forest type: Oak-hickory | Elm-ash-soft maple | Maple-birch | Aspen | Paper birch | Exotic | Non-stocked |
|---|---|---|---|---|---|---|---|
| Stand area (acres) | | | | | | | |
| More than 60 | 895.0 | 229.9 | 1,484.2 | 954.5 | 163.0 | 2.2 | 30.3 |
| 10-60 | 1,556.3 | 633.9 | 1,924.6 | 1,710.7 | 367.1 | -- | 75.1 |
| Less than 10 | 407.4 | 376.8 | 588.1 | 596.3 | 111.5 | -- | 55.0 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |
| Growing-stock volume (cubic feet/acre) | | | | | | | |
| More than 1,000 | 1,346.4 | 506.2 | 2,447.8 | 1,235.2 | 340.3 | -- | -- |
| 400-1,000 | 1,027.7 | 434.4 | 1,076.9 | 999.6 | 219.2 | -- | 1.9 |
| Less than 400 | 484.6 | 300.0 | 472.2 | 1,026.7 | 82.1 | 2.2 | 158.5 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |
| Sawtimber volume (board feet/acre) | | | | | | | |
| More than 2,500 | 1,436.6 | 414.8 | 1,918.4 | 525.9 | 159.8 | -- | -- |
| 700-2,500 | 849.5 | 446.5 | 1,336.9 | 1,083.0 | 233.4 | -- | 12.7 |
| Less than 700 | 572.6 | 379.3 | 741.6 | 1,652.6 | 248.4 | 2.2 | 147.7 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |
| Percent cull trees (percent) | | | | | | | |
| Less than 20 | 1,476.6 | 822.8 | 2,709.4 | 2,340.1 | 470.1 | -- | 32.4 |
| 20-50 | 899.2 | 271.6 | 883.5 | 427.7 | 119.2 | 2.2 | 13.0 |
| More than 50 | 482.9 | 146.2 | 404.0 | 493.7 | 52.3 | -- | 115.0 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |
| Average d.b.h. of growing-stock trees (inches) | | | | | | | |
| More than 9 | 1,657.3 | 449.7 | 1,640.9 | 758.2 | 141.2 | -- | 40.2 |
| 6-9 | 1,069.2 | 704.6 | 2,183.3 | 2,008.5 | 459.3 | -- | 51.6 |
| Less than 6 | 132.2 | 86.3 | 172.7 | 494.8 | 41.1 | 2.2 | 68.6 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |
| Average merchantable height of growing-stock trees (feet) | | | | | | | |
| More than 28 | 2,346.9 | 862.0 | 3,345.8 | 2,302.7 | 504.2 | -- | 62.0 |
| 16-28 | 411.7 | 321.3 | 521.3 | 585.9 | 118.2 | 2.2 | 29.8 |
| Less than 16 | 100.1 | 57.3 | 129.8 | 372.9 | 19.2 | -- | 68.6 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |
| Distance to road (miles) | | | | | | | |
| Less than 1/4 | 1,532.7 | 570.6 | 1,865.2 | 1,511.2 | 318.9 | 2.2 | 88.6 |
| 1/4-3/4 | 1,255.7 | 562.1 | 1,742.6 | 1,417.3 | 264.4 | -- | 66.4 |
| More than 3/4 | 70.3 | 107.9 | 389.1 | 333.0 | 58.3 | -- | 5.4 |
| All classes | 2,858.7 | 1,240.6 | 3,996.9 | 3,261.5 | 641.6 | 2.2 | 160.4 |

Table 7.--Area of timberland by forest type and operability class, Wisconsin, 1983

(In thousand acres)

| Forest type | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Jack pine | 546.5 | -- | 210.7 | 164.2 | 171.6 |
| Red pine | 478.2 | 12.8 | 149.0 | 191.3 | 125.1 |
| White pine | 225.6 | 3.7 | 109.5 | 88.3 | 24.1 |
| Balsam fir | 419.4 | -- | 173.3 | 128.0 | 118.1 |
| White spruce | 61.4 | -- | 28.6 | 14.6 | 18.2 |
| Black spruce | 273.0 | -- | 23.4 | 65.9 | 183.7 |
| Northern white-cedar | 370.7 | 1.9 | 201.4 | 118.9 | 48.5 |
| Tamarack | 222.7 | -- | 27.4 | 76.9 | 118.4 |
| Oak-hickory | 2,858.7 | 78.7 | 1,500.1 | 789.5 | 490.4 |
| Elm-ash-soft maple | 1,240.6 | 12.5 | 464.0 | 463.7 | 300.4 |
| Maple-birch | 3,996.9 | 124.1 | 2,018.1 | 1,151.0 | 703.7 |
| Aspen | 3,261.5 | 23.8 | 942.4 | 1,021.3 | 1,274.0 |
| Paper birch | 641.6 | 3.4 | 270.7 | 225.0 | 142.5 |
| Exotic | 2.2 | -- | -- | -- | 2.2 |
| Nonstocked | 160.4 | -- | -- | -- | 160.4 |
| All types | 14,759.4 | 260.9 | 6,118.6 | 4,498.6 | 3,881.3 |

Table 8.--Area of timberland in operability class II (medium) by limiting factor and forest type, Wisconsin, 1983

(In thousand acres)

| Limiting factor | All types | Forest type: Jack pine | Red pine | White pine | Balsam fir | White spruce | Black spruce |
|---|---|---|---|---|---|---|---|
| 1 | 413.0 | 10.9 | 22.0 | 24.1 | 3.6 | -- | -- |
| 2 | 21.5 | 2.3 | -- | -- | -- | -- | -- |
| 3 | 14.9 | -- | -- | -- | -- | -- | -- |
| 4 | 67.5 | -- | -- | -- | -- | -- | -- |
| 5 | 237.1 | 5.5 | 30.8 | 3.9 | 2.1 | 10.0 | -- |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 309.6 | 3.7 | -- | 7.7 | -- | -- | -- |
| 1 & 2 | 69.6 | 1.7 | -- | 1.8 | 7.2 | -- | 1.7 |
| 1 & 3 | 16.6 | -- | -- | -- | -- | -- | -- |
| 1 & 4 | 170.9 | 2.2 | 1.8 | 2.1 | -- | -- | -- |
| 1 & 5 | 360.4 | 19.4 | 33.4 | 16.7 | 9.2 | 1.7 | 3.5 |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 342.0 | 3.1 | 7.0 | 8.9 | 7.4 | -- | -- |
| 2 & 3 | 29.1 | -- | -- | -- | -- | -- | -- |
| 2 & 4 | 34.2 | 2.4 | -- | -- | -- | -- | -- |
| 2 & 5 | 16.3 | -- | -- | -- | 10.4 | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | 33.9 | -- | -- | -- | 1.9 | -- | -- |
| 3 & 4 | 4.5 | -- | -- | -- | -- | -- | -- |
| 3 & 5 | 144.9 | 1.9 | 4.1 | -- | -- | 1.7 | -- |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | 17.3 | -- | -- | -- | -- | -- | -- |
| 4 & 5 | 19.7 | -- | -- | -- | -- | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | 110.8 | 1.8 | -- | -- | -- | -- | -- |
| 5 & 6 | 24.8 | 2.2 | 2.6 | -- | 3.8 | -- | -- |
| 5 & 7 | 246.6 | 9.0 | 2.2 | 7.6 | 5.8 | 1.7 | -- |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | 88.2 | 1.9 | -- | -- | 5.8 | -- | -- |
| 1 & 2 & 4 | 78.9 | 1.6 | 1.0 | -- | -- | -- | -- |
| 1 & 2 & 5 | 13.7 | 6.2 | -- | -- | 1.9 | -- | -- |
| 1 & 2 & 6 | 1.6 | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | 69.3 | 1.9 | 3.6 | -- | 3.6 | -- | -- |
| 1 & 3 & 4 | 5.5 | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 5 | 259.1 | 8.1 | 6.3 | -- | 1.9 | -- | -- |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | 22.1 | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 5 | 55.8 | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | 147.1 | 2.2 | -- | 2.3 | -- | -- | -- |
| 1 & 5 & 6 | 59.0 | 1.7 | 7.7 | 13.0 | 3.7 | -- | -- |
| 1 & 5 & 7 | 264.0 | 1.8 | 5.7 | 5.8 | 13.3 | -- | 1.7 |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | 18.3 | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 5 | 29.0 | 4.1 | 2.4 | -- | -- | -- | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | 43.9 | -- | -- | 1.7 | 1.9 | -- | -- |
| 2 & 4 & 5 | 3.1 | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | 45.6 | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 6 | 5.4 | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 7 | 2.7 | -- | -- | -- | -- | 2.7 | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | 27.0 | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | 7.7 | -- | -- | -- | -- | -- | -- |
| 3 & 5 & 6 | 84.4 | 32.8 | -- | -- | -- | -- | 1.7 |
| 3 & 5 & 7 | 222.2 | 9.9 | 1.8 | -- | -- | -- | -- |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | 1.9 | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 7 | 35.5 | -- | -- | -- | 2.0 | -- | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | 36.6 | 1.7 | -- | -- | 1.8 | -- | -- |
| 4 or more | 1,785.8 | 70.7 | 16.6 | 13.9 | 86.0 | 10.8 | 14.8 |
| All factors | 6,118.6 | 210.7 | 149.0 | 109.5 | 173.3 | 28.6 | 23.4 |

(Table 8 continued on next page)

(Table 8 continued)

| Limiting factor | Northern white-cedar | Tamarack | Oak-hickory | Elm-ash-soft maple | Maple-birch | Aspen | Paper birch |
|---|---|---|---|---|---|---|---|
| | Forest type | | | | | | |
| 1 | -- | -- | 122.3 | 22.8 | 153.7 | 37.5 | 16.1 |
| 2 | -- | -- | 13.7 | 1.9 | 3.6 | -- | -- |
| 3 | -- | -- | 2.4 | -- | 4.4 | 8.1 | -- |
| 4 | -- | -- | 25.2 | 8.0 | 32.4 | 1.9 | -- |
| 5 | 5.4 | -- | 34.0 | 4.1 | 112.6 | 21.6 | 7.1 |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 5.5 | -- | 76.9 | 21.5 | 157.9 | 29.2 | 7.2 |
| 1 & 2 | 1.8 | -- | 43.8 | 1.9 | 1.7 | 5.4 | 2.6 |
| 1 & 3 | -- | -- | 5.1 | -- | 2.5 | 7.3 | 1.7 |
| 1 & 4 | -- | -- | 76.8 | 8.8 | 70.2 | 6.3 | 2.7 |
| 1 & 5 | 8.5 | 1.9 | 44.2 | 31.5 | 110.0 | 54.0 | 26.4 |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 5.2 | -- | 103.6 | 24.9 | 131.5 | 41.4 | 9.0 |
| 2 & 3 | -- | -- | 4.5 | 2.5 | 4.4 | 13.1 | 4.6 |
| 2 & 4 | -- | -- | 21.9 | 1.7 | 8.2 | -- | -- |
| 2 & 5 | -- | -- | 2.8 | -- | 3.1 | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | -- | -- | 10.3 | 1.7 | 11.0 | 6.3 | 2.7 |
| 3 & 4 | -- | -- | 4.5 | -- | -- | -- | -- |
| 3 & 5 | -- | -- | 17.1 | 8.2 | 54.1 | 47.0 | 10.8 |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | -- | -- | 2.6 | -- | 3.7 | 9.2 | 1.8 |
| 4 & 5 | -- | -- | 7.2 | 1.7 | 10.8 | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | 1.8 | -- | 51.2 | 6.2 | 43.3 | 6.5 | -- |
| 5 & 6 | 2.0 | -- | 8.7 | 1.8 | 3.7 | -- | -- |
| 5 & 7 | 2.2 | -- | 58.7 | 4.1 | 110.3 | 34.0 | 11.0 |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | -- | -- | 24.0 | 13.7 | 16.3 | 20.9 | 5.6 |
| 1 & 2 & 4 | -- | -- | 51.0 | 2.0 | 21.4 | -- | 1.9 |
| 1 & 2 & 5 | -- | -- | 5.6 | -- | -- | -- | -- |
| 1 & 2 & 6 | 1.6 | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | -- | -- | 31.8 | 8.2 | 12.4 | 7.8 | -- |
| 1 & 3 & 4 | -- | -- | 5.5 | -- | -- | -- | -- |
| 1 & 3 & 5 | -- | -- | 29.4 | 22.8 | 76.4 | 81.4 | 32.8 |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | -- | -- | 2.3 | 4.5 | 7.7 | 7.6 | -- |
| 1 & 4 & 5 | 7.5 | -- | 10.9 | 7.1 | 26.8 | 3.5 | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | 1.8 | -- | 65.5 | 9.3 | 51.1 | 8.0 | 6.9 |
| 1 & 5 & 6 | 8.0 | 1.6 | 6.7 | 9.2 | 2.0 | -- | 5.4 |
| 1 & 5 & 7 | 3.7 | 1.9 | 55.9 | 18.5 | 82.5 | 56.2 | 17.0 |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | -- | -- | 9.8 | 1.9 | 1.9 | 2.8 | 1.9 |
| 2 & 3 & 5 | -- | -- | 4.4 | 4.6 | 11.8 | 1.7 | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | -- | 2.2 | 10.2 | -- | 12.9 | 15.0 | -- |
| 2 & 4 & 5 | -- | -- | 3.1 | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | 1.7 | -- | 32.0 | 2.5 | 9.4 | -- | -- |
| 2 & 5 & 6 | -- | -- | 3.2 | 2.2 | -- | -- | -- |
| 2 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | -- | -- | 8.3 | -- | 12.7 | -- | 6.0 |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | -- | -- | 1.8 | -- | 1.8 | 4.1 | -- |
| 3 & 5 & 6 | 12.3 | -- | 8.4 | -- | 19.1 | 6.4 | 3.7 |
| 3 & 5 & 7 | 1.8 | 2.0 | 21.9 | 10.6 | 78.1 | 76.0 | 20.1 |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | -- | -- | -- | -- | 1.9 | -- | -- |
| 4 & 5 & 7 | -- | -- | 2.2 | -- | 24.6 | 6.7 | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | 5.2 | -- | 5.8 | 6.8 | 15.3 | -- | -- |
| 4 or more | 125.4 | 17.8 | 362.9 | 186.8 | 498.9 | 315.5 | 65.7 |
| All factors | 201.4 | 27.4 | 1,500.1 | 464.0 | 2,018.1 | 942.4 | 270.7 |

Table 9.--Area of timberland in operability class III (poor) by limiting factor and forest type, Wisconsin, 1983

(In thousand acres)

| Limiting factor | All types | Forest type: Jack pine | Red pine | White pine | Balsam fir | White spruce | Black spruce |
|---|---|---|---|---|---|---|---|
| 1 | 1,188.6 | 46.6 | 63.6 | 52.9 | 51.6 | 10.7 | 22.7 |
| 2 | 78.6 | -- | -- | -- | -- | -- | 1.9 |
| 3 | 1,089.8 | 58.5 | 43.6 | 3.9 | 13.0 | -- | 17.2 |
| 4 | 342.3 | 3.3 | 1.8 | 7.6 | -- | -- | -- |
| 5 | 17.3 | 1.9 | 2.5 | -- | 1.8 | -- | 1.7 |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 626.7 | 6.0 | 16.1 | -- | 32.5 | 2.0 | 1.7 |
| 1 & 2 | 39.7 | 2.2 | -- | 2.5 | -- | -- | -- |
| 1 & 3 | 220.0 | 8.9 | 20.9 | 11.2 | -- | -- | 2.0 |
| 1 & 4 | 81.7 | 3.5 | -- | 4.6 | -- | -- | -- |
| 1 & 5 | 2.0 | -- | -- | -- | -- | -- | -- |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 60.8 | 1.9 | -- | 2.0 | 1.8 | -- | 7.2 |
| 2 & 3 | 127.8 | 5.7 | 1.8 | -- | 12.7 | -- | 4.0 |
| 2 & 4 | 61.2 | -- | -- | -- | -- | -- | -- |
| 2 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | 5.9 | -- | -- | -- | -- | -- | -- |
| 3 & 4 | 57.1 | -- | -- | -- | -- | -- | 1.9 |
| 3 & 5 | 72.8 | 13.1 | 17.6 | -- | 3.8 | -- | 1.8 |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | 128.5 | -- | 1.9 | -- | 3.7 | -- | -- |
| 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | 19.7 | -- | -- | -- | -- | -- | -- |
| 5 & 6 | -- | - | -- | -- | -- | -- | -- |
| 5 & 7 | -- | - | -- | -- | -- | -- | -- |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | 48.0 | 2.2 | -- | -- | 1.9 | -- | 1.9 |
| 1 & 2 & 4 | 12.9 | -- | -- | -- | 1.6 | -- | -- |
| 1 & 2 & 5 | 2.4 | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 4 | 10.1 | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 5 | 16.3 | 2.3 | 8.0 | -- | -- | -- | -- |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | 6.6 | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 7 | 3.6 | -- | -- | -- | -- | -- | -- |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | 51.1 | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 5 | 16.8 | 2.1 | 1.9 | -- | -- | -- | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | 10.9 | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | 1.7 | -- | -- | -- | -- | -- | -- |
| 3 & 5 & 6 | 9.3 | 1.8 | -- | -- | 1.9 | -- | -- |
| 3 & 5 & 7 | 3.5 | -- | -- | -- | 1.7 | -- | -- |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 or more | 84.9 | 4.2 | 11.6 | 3.6 | -- | 1.9 | 1.9 |
| All factors | 4,498.6 | 164.2 | 191.3 | 88.3 | 128.0 | 14.6 | 65.9 |

(Table 9 continued on next page)

(Table 9 continued)

| | Forest type | | | | | | |
|---|---|---|---|---|---|---|---|
| Limiting factor | Northern white-cedar | Tamarack | Oak-hickory | Elm-ash-soft maple | Maple-birch | Aspen | Paper birch |
| 1 | 24.7 | 8.2 | 196.2 | 168.4 | 315.2 | 185.8 | 42.0 |
| 2 | -- | 1.7 | 27.2 | 10.2 | 10.7 | 25.1 | 1.8 |
| 3 | 29.0 | 27.7 | 155.6 | 55.8 | 195.9 | 402.1 | 87.5 |
| 4 | 1.8 | -- | 167.4 | 22.2 | 102.3 | 26.6 | 9.3 |
| 5 | -- | -- | 5.8 | -- | 1.7 | 1.9 | -- |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 30.9 | 1.8 | 39.2 | 58.2 | 305.3 | 108.3 | 24.7 |
| 1 & 2 | -- | 3.7 | 8.7 | 11.7 | 7.2 | 3.7 | -- |
| 1 & 3 | 8.1 | 5.9 | 25.0 | 15.0 | 26.6 | 86.1 | 10.3 |
| 1 & 4 | 2.6 | -- | 24.0 | 12.0 | 21.3 | 9.0 | 4.7 |
| 1 & 5 | -- | -- | -- | -- | 2.0 | -- | -- |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 1.8 | 1.9 | 6.2 | 12.3 | 15.1 | 7.3 | 3.3 |
| 2 & 3 | -- | 5.5 | 15.4 | 21.6 | 22.6 | 29.8 | 8.7 |
| 2 & 4 | -- | -- | 37.4 | 4.7 | 14.8 | 4.3 | -- |
| 2 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | -- | -- | 2.5 | 1.7 | -- | 1.7 | -- |
| 3 & 4 | -- | -- | 13.3 | 4.4 | 18.5 | 12.2 | 6.8 |
| 3 & 5 | 3.5 | 8.8 | 2.2 | 4.1 | 7.4 | 8.9 | 1.6 |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | 3.5 | 5.4 | 9.9 | 5.3 | 27.3 | 52.8 | 18.7 |
| 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | -- | -- | 4.7 | -- | 5.5 | 7.6 | 1.9 |
| 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | -- | -- | 4.0 | 24.5 | 9.7 | 1.9 | 1.9 |
| 1 & 2 & 4 | -- | -- | 7.0 | -- | 4.3 | -- | -- |
| 1 & 2 & 5 | -- | -- | -- | 2.4 | -- | -- | -- |
| 1 & 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 4 | 1.8 | -- | 2.2 | 2.2 | 1.7 | 2.2 | -- |
| 1 & 3 & 5 | -- | 2.5 | 1.8 | -- | -- | 1.7 | -- |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | -- | -- | -- | 2.7 | -- | 3.9 | -- |
| 1 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 7 | -- | -- | 1.7 | -- | -- | 1.9 | -- |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | -- | 2.1 | 27.9 | -- | 12.8 | 8.3 | -- |
| 2 & 3 & 5 | -- | -- | -- | 6.2 | 1.8 | 4.8 | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | 1.7 | -- | -- | 1.8 | 3.7 | 3.7 | -- |
| 2 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | -- | -- | -- | 1.7 | -- | -- | -- |
| 3 & 5 & 6 | 5.6 | -- | -- | -- | -- | -- | -- |
| 3 & 5 & 7 | -- | -- | -- | -- | -- | -- | 1.8 |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 or more | 3.9 | 1.7 | 4.2 | 14.6 | 17.6 | 19.7 | -- |
| All factors | 118.9 | 76.9 | 789.5 | 463.7 | 1,151.0 | 1,021.3 | 225.0 |

Table 10.--Area of timberland by forest type, average growing-stock volume and operability class, Wisconsin, 1983

(In thousand acres)

| Forest type and average growing-stock volume per acre (cu.ft. per acre) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Jack pine | | | | | |
| More than 1,000 | 199.6 | -- | 137.8 | 57.4 | 4.4 |
| 400-1,000 | 204.7 | -- | 72.9 | 90.4 | 41.4 |
| Less than 400 | 142.2 | -- | -- | 16.4 | 125.8 |
| All classes | 546.5 | -- | 210.7 | 164.2 | 171.6 |
| Red pine | | | | | |
| More than 1,000 | 321.2 | 12.8 | 142.0 | 164.3 | 2.1 |
| 400-1,000 | 41.6 | -- | 7.0 | 11.7 | 22.9 |
| Less than 400 | 115.4 | -- | -- | 15.3 | 100.1 |
| All classes | 478.2 | 12.8 | 149.0 | 191.3 | 125.1 |
| White pine | | | | | |
| More than 1,000 | 150.2 | 3.7 | 96.1 | 50.4 | -- |
| 400-1,000 | 54.2 | -- | 13.4 | 31.8 | 9.0 |
| Less than 400 | 21.2 | -- | -- | 6.1 | 15.1 |
| All classes | 225.6 | 3.7 | 109.5 | 88.3 | 24.1 |
| Balsam fir | | | | | |
| More than 1,000 | 153.7 | -- | 83.1 | 66.3 | 4.3 |
| 400-1,000 | 187.0 | -- | 90.2 | 45.5 | 51.3 |
| Less than 400 | 78.7 | -- | -- | 16.2 | 62.5 |
| All classes | 419.4 | -- | 173.3 | 128.0 | 118.1 |
| White spruce | | | | | |
| More than 1,000 | 36.7 | -- | 25.9 | 10.8 | -- |
| 400-1,000 | 8.1 | -- | 2.7 | 3.8 | 1.6 |
| Less than 400 | 16.6 | -- | -- | -- | 16.6 |
| All classes | 61.4 | -- | 28.6 | 14.6 | 18.2 |
| Black spruce | | | | | |
| More than 1,000 | 38.9 | -- | 11.2 | 27.7 | -- |
| 400-1,000 | 63.7 | -- | 12.2 | 28.5 | 23.0 |
| Less than 400 | 170.4 | -- | -- | 9.7 | 160.7 |
| All classes | 273.0 | -- | 23.4 | 65.9 | 183.7 |
| Northern white-cedar | | | | | |
| More than 1,000 | 216.5 | 1.9 | 141.5 | 73.1 | -- |
| 400-1,000 | 123.1 | -- | 59.9 | 40.2 | 23.0 |
| Less than 400 | 31.1 | -- | -- | 5.6 | 25.5 |
| All classes | 370.7 | 1.9 | 201.4 | 118.9 | 48.5 |
| Tamarack | | | | | |
| More than 1,000 | 28.9 | -- | 11.5 | 15.8 | 1.6 |
| 400-1,000 | 86.8 | -- | 15.9 | 46.4 | 24.5 |
| Less than 400 | 107.0 | -- | -- | 14.7 | 92.3 |
| All classes | 222.7 | -- | 27.4 | 76.9 | 118.4 |

(Table 10 continued on next page)

(Table 10 continued)

| Forest type and average growing-stock volume per acre (cu.ft. per acre) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Oak-hickory | | | | | |
| More than 1,000 | 1,346.4 | 78.7 | 937.6 | 321.8 | 8.3 |
| 400-1,000 | 1,027.7 | -- | 562.5 | 333.4 | 131.8 |
| Less than 400 | 484.6 | -- | -- | 134.3 | 350.3 |
| All classes | 2,858.7 | 78.7 | 1,500.1 | 789.5 | 490.4 |
| Elm-ash-soft maple | | | | | |
| More than 1,000 | 506.2 | 12.5 | 306.0 | 180.2 | 7.5 |
| 400-1,000 | 434.4 | -- | 158.0 | 184.1 | 92.3 |
| Less than 400 | 300.0 | -- | -- | 99.4 | 200.6 |
| All classes | 1,240.6 | 12.5 | 464.0 | 463.7 | 300.4 |
| Maple-birch | | | | | |
| More than 1,000 | 2,447.8 | 124.1 | 1,647.4 | 644.5 | 31.8 |
| 400-1,000 | 1,076.9 | -- | 370.7 | 401.3 | 304.9 |
| Less than 400 | 472.2 | -- | -- | 105.2 | 367.0 |
| All classes | 3,996.9 | 124.1 | 2,018.1 | 1,151.0 | 703.7 |
| Aspen | | | | | |
| More than 1,000 | 1,235.2 | 23.8 | 693.3 | 472.9 | 45.2 |
| 400-1,000 | 999.6 | -- | 249.1 | 445.4 | 305.1 |
| Less than 400 | 1,026.7 | -- | -- | 103.0 | 923.7 |
| All classes | 3,261.5 | 23.8 | 942.4 | 1,021.3 | 1,274.0 |
| Paper birch | | | | | |
| More than 1,000 | 340.3 | 3.4 | 216.1 | 111.3 | 9.5 |
| 400-1,000 | 219.2 | -- | 54.6 | 101.3 | 63.3 |
| Less than 400 | 82.1 | -- | -- | 12.4 | 69.7 |
| All classes | 641.6 | 3.4 | 270.7 | 225.0 | 142.5 |
| Exotic | | | | | |
| More than 1,000 | -- | -- | -- | -- | -- |
| 400-1,000 | -- | -- | -- | -- | -- |
| Less than 400 | 2.2 | -- | -- | -- | 2.2 |
| All classes | 2.2 | -- | -- | -- | 2.2 |
| Nonstocked | | | | | |
| More than 1,000 | -- | -- | -- | -- | -- |
| 400-1,000 | 1.9 | -- | -- | -- | 1.9 |
| Less than 400 | 158.5 | -- | -- | -- | 158.5 |
| All classes | 160.4 | -- | -- | -- | 160.4 |
| All types | | | | | |
| More than 1,000 | 7,021.6 | 260.9 | 4,449.5 | 2,196.5 | 114.7 |
| 400-1,000 | 4,528.9 | -- | 1,669.1 | 1,763.8 | 1,096.0 |
| Less than 400 | 3,208.9 | -- | -- | 538.3 | 2,670.6 |
| All classes | 14,759.4 | 260.9 | 6,118.6 | 4,498.6 | 3,881.3 |

Table 11.--Area of timberland by forest type, stand-age class and operability class, Wisconsin, 1983

(In thousand acres)

| Forest type and stand-age class (years) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Jack pine | | | | | |
| less than 21 | 132.8 | -- | -- | 4.8 | 128.0 |
| 21-40 | 190.6 | -- | 48.4 | 98.6 | 43.6 |
| 41-60 | 202.6 | -- | 143.7 | 58.9 | -- |
| 61-80 | 18.6 | -- | 16.7 | 1.9 | -- |
| 81-100 | 1.9 | -- | 1.9 | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 546.5 | -- | 210.7 | 164.2 | 171.6 |
| Red pine | | | | | |
| less than 21 | 158.3 | -- | -- | 41.5 | 116.8 |
| 21-40 | 205.6 | 1.8 | 99.5 | 96.0 | 8.3 |
| 41-60 | 78.5 | 8.2 | 33.0 | 37.3 | -- |
| 61-80 | 15.1 | 1.0 | 10.5 | 3.6 | -- |
| 81-100 | 17.5 | 1.8 | 4.4 | 11.3 | -- |
| 101-120 | 3.2 | -- | 1.6 | 1.6 | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 478.2 | 12.8 | 149.0 | 191.3 | 125.1 |
| White pine | | | | | |
| less than 21 | 31.2 | -- | -- | 7.1 | 24.1 |
| 21-40 | 29.1 | -- | 10.3 | 18.8 | -- |
| 41-60 | 44.8 | -- | 23.5 | 21.3 | -- |
| 61-80 | 55.3 | -- | 36.0 | 19.3 | -- |
| 81-100 | 35.3 | -- | 15.9 | 19.4 | -- |
| 101-120 | 10.1 | 1.9 | 5.8 | 2.4 | -- |
| More than 120 | 19.8 | 1.8 | 18.0 | -- | -- |
| All ages | 225.6 | 3.7 | 109.5 | 88.3 | 24.1 |
| Balsam fir | | | | | |
| less than 21 | 79.6 | -- | -- | -- | 79.6 |
| 21-40 | 93.0 | -- | 32.4 | 24.0 | 36.6 |
| 41-60 | 150.3 | -- | 86.3 | 62.1 | 1.9 |
| 61-80 | 65.7 | -- | 34.1 | 31.6 | -- |
| 81-100 | 16.4 | -- | 11.7 | 4.7 | -- |
| 101-120 | 7.5 | -- | 3.7 | 3.8 | -- |
| More than 120 | 6.9 | -- | 5.1 | 1.8 | -- |
| All ages | 419.4 | -- | 173.3 | 128.0 | 118.1 |
| White spruce | | | | | |
| less than 21 | 19.8 | -- | 1.7 | 1.9 | 16.2 |
| 21-40 | 24.6 | -- | 20.4 | 2.2 | 2.0 |
| 41-60 | 15.0 | -- | 6.5 | 8.5 | -- |
| 61-80 | 2.0 | -- | -- | 2.0 | -- |
| 81-100 | -- | -- | -- | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 61.4 | -- | 28.6 | 14.6 | 18.2 |

(Table 11 continued on next page)

(Table 11 continued)

| Forest type and stand-age class (years) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Black spruce | | | | | |
| less than 21 | 71.0 | -- | -- | -- | 71.0 |
| 21-40 | 106.8 | -- | 1.7 | 7.6 | 97.5 |
| 41-60 | 41.9 | -- | 6.0 | 20.7 | 15.2 |
| 61-80 | 39.0 | -- | 6.9 | 32.1 | -- |
| 81-100 | 12.4 | -- | 8.8 | 3.6 | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | 1.9 | -- | -- | 1.9 | -- |
| All ages | 273.0 | -- | 23.4 | 65.9 | 183.7 |
| Northern white-cedar | | | | | |
| less than 21 | 24.3 | -- | 1.8 | 1.8 | 20.7 |
| 21-40 | 26.1 | -- | -- | 6.1 | 20.0 |
| 41-60 | 80.9 | -- | 55.4 | 17.7 | 7.8 |
| 61-80 | 68.4 | -- | 37.8 | 30.6 | -- |
| 81-100 | 95.5 | -- | 54.6 | 40.9 | -- |
| 101-120 | 30.8 | 1.9 | 19.9 | 9.0 | -- |
| More than 120 | 44.7 | -- | 31.9 | 12.8 | -- |
| All ages | 370.7 | 1.9 | 201.4 | 118.9 | 48.5 |
| Tamarack | | | | | |
| less than 21 | 71.1 | -- | -- | -- | 71.1 |
| 21-40 | 53.8 | -- | -- | 6.5 | 47.3 |
| 41-60 | 38.6 | -- | 3.5 | 35.1 | -- |
| 61-80 | 35.2 | -- | 16.2 | 19.0 | -- |
| 81-100 | 16.6 | -- | 7.7 | 8.9 | -- |
| 101-120 | 3.8 | -- | -- | 3.8 | -- |
| More than 120 | 3.6 | -- | -- | 3.6 | -- |
| All ages | 222.7 | -- | 27.4 | 76.9 | 118.4 |
| Oak-hickory | | | | | |
| less than 21 | 446.3 | -- | 3.1 | 1.8 | 441.4 |
| 21-40 | 221.8 | -- | 82.7 | 90.1 | 49.0 |
| 41-60 | 761.1 | 25.1 | 453.4 | 282.6 | -- |
| 61-80 | 557.9 | 22.8 | 371.7 | 163.4 | -- |
| 81-100 | 426.8 | 14.8 | 303.8 | 108.2 | -- |
| 101-120 | 208.9 | 8.3 | 146.0 | 54.6 | -- |
| More than 120 | 235.9 | 7.7 | 139.4 | 88.8 | -- |
| All ages | 2,858.7 | 78.7 | 1,500.1 | 789.5 | 490.4 |
| Elm-ash-soft maple | | | | | |
| less than 21 | 249.9 | -- | -- | 4.5 | 245.4 |
| 21-40 | 204.9 | -- | 68.0 | 85.5 | 51.4 |
| 41-60 | 284.2 | 1.9 | 110.4 | 168.3 | 3.6 |
| 61-80 | 262.8 | 6.4 | 149.9 | 106.5 | -- |
| 81-100 | 149.1 | 2.3 | 76.0 | 70.8 | -- |
| 101-120 | 50.2 | 1.9 | 33.6 | 14.7 | -- |
| More than 120 | 39.5 | -- | 26.1 | 13.4 | -- |
| All ages | 1,240.6 | 12.5 | 464.0 | 463.7 | 300.4 |

(Table 11 continued on next page)

(Table 11 continued)

| Forest type and stand-age class (years) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Maple-birch | | | | | |
| less than 21 | 577.6 | -- | 2.0 | 5.1 | 570.5 |
| 21-40 | 490.8 | 6.2 | 162.7 | 192.1 | 129.8 |
| 41-60 | 1,294.2 | 18.1 | 809.5 | 463.2 | 3.4 |
| 61-80 | 721.1 | 30.3 | 497.2 | 193.6 | -- |
| 81-100 | 441.0 | 26.4 | 275.6 | 139.0 | -- |
| 101-120 | 215.9 | 14.8 | 120.5 | 80.6 | -- |
| More than 120 | 256.3 | 28.3 | 150.6 | 77.4 | -- |
| All ages | 3,996.9 | 124.1 | 2,018.1 | 1,151.0 | 703.7 |
| Aspen | | | | | |
| less than 21 | 1,102.3 | -- | 6.3 | 15.7 | 1,080.3 |
| 21-40 | 783.5 | -- | 221.3 | 368.5 | 193.7 |
| 41-60 | 1,107.4 | 14.2 | 535.9 | 557.3 | -- |
| 61-80 | 225.8 | 9.6 | 149.7 | 66.5 | -- |
| 81-100 | 42.5 | -- | 29.2 | 13.3 | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 3,261.5 | 23.8 | 942.4 | 1,021.3 | 1,274.0 |
| Paper birch | | | | | |
| less than 21 | 110.4 | -- | -- | -- | 110.4 |
| 21-40 | 154.8 | -- | 43.7 | 81.3 | 29.8 |
| 41-60 | 279.1 | 3.1 | 161.1 | 112.6 | 2.3 |
| 61-80 | 91.3 | -- | 64.0 | 27.3 | -- |
| 81-100 | 2.2 | 0.3 | -- | 1.9 | -- |
| 101-120 | 3.8 | -- | 1.9 | 1.9 | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 641.6 | 3.4 | 270.7 | 225.0 | 142.5 |
| Exotic | | | | | |
| less than 21 | 2.2 | -- | -- | -- | 2.2 |
| 21-40 | -- | -- | -- | -- | -- |
| 41-60 | -- | -- | -- | -- | -- |
| 61-80 | -- | -- | -- | -- | -- |
| 81-100 | -- | -- | -- | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 2.2 | -- | -- | -- | 2.2 |
| Nonstocked | | | | | |
| less than 21 | 160.4 | -- | -- | -- | 160.4 |
| 21-40 | -- | -- | -- | -- | -- |
| 41-60 | -- | -- | -- | -- | -- |
| 61-80 | -- | -- | -- | -- | -- |
| 81-100 | -- | -- | -- | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 160.4 | -- | -- | -- | 160.4 |
| All types | | | | | |
| less than 21 | 3,237.2 | -- | 14.9 | 84.2 | 3,138.1 |
| 21-40 | 2,585.4 | 8.0 | 791.1 | 1,077.3 | 709.0 |
| 41-60 | 4,378.6 | 70.6 | 2,428.2 | 1,845.6 | 34.2 |
| 61-80 | 2,158.2 | 70.1 | 1,390.7 | 697.4 | -- |
| 81-100 | 1,257.2 | 45.6 | 789.6 | 422.0 | -- |
| 101-120 | 534.2 | 28.8 | 333.0 | 172.4 | -- |
| More than 120 | 608.6 | 37.8 | 371.1 | 199.7 | -- |
| All ages | 14,759.4 | 260.9 | 6,118.6 | 4,498.6 | 3,881.3 |

Table 12.--Area of timberland by forest type, ownership class and operability class, Wisconsin, 1983

(In thousand acres)

| Forest type and ownership class | All classes | Operability class: I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
|---|---|---|---|---|---|
| Jack Pine | | | | | |
| National forest | 50.3 | -- | 47.9 | 1.9 | 0.5 |
| Other federal | 24.6 | -- | 11.0 | 2.2 | 11.4 |
| Indian | 5.6 | -- | 4.0 | 1.6 | -- |
| State | 33.4 | -- | 7.3 | 8.3 | 17.8 |
| County and municipal | 137.2 | -- | 44.1 | 49.3 | 43.8 |
| Forest industry | 69.1 | -- | 19.2 | 24.9 | 25.0 |
| Farmer | 44.6 | -- | 20.7 | 15.0 | 8.9 |
| Miscellaneous private | 181.7 | -- | 56.5 | 61.0 | 64.2 |
| All owners | 546.5 | -- | 210.7 | 164.2 | 171.6 |
| Red pine | | | | | |
| National forest | 103.4 | 9.2 | 45.0 | 25.7 | 23.5 |
| Other federal | 9.0 | -- | 2.1 | -- | 6.9 |
| Indian | 8.9 | -- | 7.1 | 1.8 | -- |
| State | 29.1 | -- | 16.0 | 9.5 | 3.6 |
| County and municipal | 80.8 | 1.8 | 23.1 | 32.5 | 23.4 |
| Forest industry | 49.7 | -- | 14.8 | 4.2 | 30.7 |
| Farmer | 35.2 | -- | 11.4 | 21.9 | 1.9 |
| Miscellaneous private | 162.1 | 1.8 | 29.5 | 95.7 | 35.1 |
| All owners | 478.2 | 12.8 | 149.0 | 191.3 | 125.1 |
| White pine | | | | | |
| National forest | 15.2 | -- | 15.2 | -- | -- |
| Other federal | 6.9 | -- | 4.4 | -- | 2.5 |
| Indian | 17.4 | 1.8 | 12.1 | 3.5 | -- |
| State | 9.6 | -- | 5.8 | 1.6 | 2.2 |
| County and municipal | 24.4 | -- | 8.7 | 13.5 | 2.2 |
| Forest industry | 16.9 | -- | 9.5 | 4.0 | 3.4 |
| Farmer | 49.0 | -- | 16.9 | 25.3 | 6.8 |
| Miscellaneous private | 86.2 | 1.9 | 36.9 | 40.4 | 7.0 |
| All owners | 225.6 | 3.7 | 109.5 | 88.3 | 24.1 |
| Balsam fir | | | | | |
| National forest | 66.0 | -- | 30.2 | 29.3 | 6.5 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 4.1 | -- | -- | 4.1 | -- |
| State | 21.7 | -- | 9.1 | 7.2 | 5.4 |
| County and municipal | 71.6 | -- | 27.3 | 27.8 | 16.5 |
| Forest industry | 42.1 | -- | 21.2 | 5.3 | 15.6 |
| Farmer | 35.6 | -- | 9.5 | 7.5 | 18.6 |
| Miscellaneous private | 178.3 | -- | 76.0 | 46.8 | 55.5 |
| All owners | 419.4 | -- | 173.3 | 128.0 | 118.1 |
| White spruce | | | | | |
| National forest | 31.2 | -- | 21.4 | 6.6 | 3.2 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | -- | -- | -- | -- | -- |
| State | 1.7 | -- | -- | -- | 1.7 |
| County and municipal | 1.8 | -- | -- | -- | 1.8 |
| Forest industry | 5.7 | -- | 1.7 | 2.0 | 2.0 |
| Farmer | -- | -- | -- | -- | -- |
| Miscellaneous private | 21.0 | -- | 5.5 | 6.0 | 9.5 |
| All owners | 61.4 | -- | 28.6 | 14.6 | 18.2 |

(Table 12 continued on next page)

(Table 12 continued)

| Forest type and ownership class | All classes | Operability class: I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
|---|---|---|---|---|---|
| Black spruce | | | | | |
| National forest | 36.5 | -- | 0.8 | 14.9 | 20.8 |
| Other federal | 2.2 | -- | -- | -- | 2.2 |
| Indian | 3.6 | -- | -- | 3.6 | -- |
| State | 28.1 | -- | 5.3 | 4.8 | 18.0 |
| County and municipal | 58.9 | -- | -- | 22.0 | 36.9 |
| Forest industry | 38.3 | -- | 6.9 | 3.7 | 27.7 |
| Farmer | 19.2 | -- | -- | 2.0 | 17.2 |
| Miscellaneous private | 86.2 | -- | 10.4 | 14.9 | 60.9 |
| All owners | 273.0 | -- | 23.4 | 65.9 | 183.7 |
| Northern white-cedar | | | | | |
| National forest | 65.6 | -- | 47.0 | 14.9 | 3.7 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 17.8 | -- | 12.7 | 3.4 | 1.7 |
| State | 18.9 | 1.9 | 11.4 | 5.6 | -- |
| County and municipal | 46.2 | -- | 24.7 | 14.3 | 7.2 |
| Forest industry | 38.0 | -- | 20.1 | 14.4 | 3.5 |
| Farmer | 57.7 | -- | 29.9 | 11.1 | 16.7 |
| Miscellaneous private | 126.5 | -- | 55.6 | 55.2 | 15.7 |
| All owners | 370.7 | 1.9 | 201.4 | 118.9 | 48.5 |
| Tamarack | | | | | |
| National forest | 16.9 | -- | 2.0 | 13.5 | 1.4 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 1.6 | -- | -- | -- | 1.6 |
| State | 22.2 | -- | 2.1 | 5.4 | 14.7 |
| County and municipal | 21.5 | -- | -- | 10.2 | 11.3 |
| Forest industry | 16.2 | -- | 2.0 | 7.1 | 7.1 |
| Farmer | 41.4 | -- | 4.0 | 11.1 | 26.3 |
| Miscellaneous private | 102.9 | -- | 17.3 | 29.6 | 56.0 |
| All owners | 222.7 | -- | 27.4 | 76.9 | 118.4 |
| Oak-hickory | | | | | |
| National forest | 45.2 | -- | 19.4 | 23.5 | 2.3 |
| Other federal | 46.6 | -- | 22.2 | 9.0 | 15.4 |
| Indian | 23.1 | 3.6 | 14.1 | 3.6 | 1.8 |
| State | 68.9 | 6.7 | 31.2 | 13.6 | 17.4 |
| County and municipal | 224.5 | 2.0 | 54.1 | 100.8 | 67.6 |
| Forest industry | 78.1 | 2.5 | 20.8 | 8.4 | 46.4 |
| Farmer | 1,262.6 | 32.8 | 798.1 | 313.7 | 118.0 |
| Miscellaneous private | 1,109.7 | 31.1 | 540.2 | 316.9 | 221.5 |
| All owners | 2,858.7 | 78.7 | 1,500.1 | 789.5 | 490.4 |
| Elm-ash-soft maple | | | | | |
| National forest | 25.3 | -- | 18.9 | 2.7 | 3.7 |
| Other federal | 27.7 | -- | 10.8 | 14.1 | 2.8 |
| Indian | 14.9 | -- | 7.2 | 5.9 | 1.8 |
| State | 60.3 | -- | 24.1 | 18.0 | 18.2 |
| County and municipal | 169.6 | 1.8 | 67.0 | 69.6 | 31.2 |
| Forest industry | 86.8 | -- | 38.7 | 25.8 | 22.3 |
| Farmer | 357.6 | 4.6 | 123.9 | 148.8 | 80.3 |
| Miscellaneous private | 498.4 | 6.1 | 173.4 | 178.8 | 140.1 |
| All owners | 1,240.6 | 12.5 | 464.0 | 463.7 | 300.4 |

(Table 12 continued on next page)

(Table 12 continued)

| Forest type and ownership class | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Maple-birch | | | | | |
| National forest | 432.1 | 16.3 | 275.4 | 136.6 | 3.8 |
| Other federal | 7.4 | -- | -- | 5.2 | 2.2 |
| Indian | 164.5 | 26.9 | 79.5 | 54.7 | 3.4 |
| State | 109.9 | -- | 52.8 | 35.3 | 21.8 |
| County and municipal | 467.1 | 4.0 | 209.6 | 172.2 | 81.3 |
| Forest industry | 440.6 | 28.1 | 225.0 | 136.7 | 50.8 |
| Farmer | 958.1 | 11.4 | 429.1 | 259.9 | 257.7 |
| Miscellaneous private | 1,417.2 | 37.4 | 746.7 | 350.4 | 282.7 |
| All owners | 3,996.9 | 124.1 | 2,018.1 | 1,151.0 | 703.7 |
| Aspen | | | | | |
| National forest | 315.9 | -- | 88.5 | 75.3 | 152.1 |
| Other federal | 40.2 | -- | 2.1 | 21.9 | 16.2 |
| Indian | 83.0 | -- | 30.9 | 33.3 | 18.8 |
| State | 140.0 | -- | 35.3 | 35.3 | 69.4 |
| County and municipal | 743.8 | 1.8 | 175.1 | 243.7 | 323.2 |
| Forest industry | 222.4 | -- | 66.0 | 49.3 | 107.1 |
| Farmer | 473.0 | 2.4 | 160.5 | 152.8 | 157.3 |
| Miscellaneous private | 1,243.2 | 19.6 | 384.0 | 409.7 | 429.9 |
| All owners | 3,261.5 | 23.8 | 942.4 | 1,021.3 | 1,274.0 |
| Paper birch | | | | | |
| National forest | 38.7 | 1.7 | 10.2 | 21.5 | 5.3 |
| Other federal | 6.1 | -- | 1.9 | 1.9 | 2.3 |
| Indian | 5.4 | -- | 3.8 | 1.6 | -- |
| State | 20.3 | -- | 13.6 | 4.9 | 1.8 |
| County and municipal | 116.1 | -- | 32.3 | 56.1 | 27.7 |
| Forest industry | 39.6 | -- | 21.9 | 15.9 | 1.8 |
| Farmer | 143.2 | -- | 58.6 | 33.2 | 51.4 |
| Miscellaneous private | 272.2 | 1.7 | 128.4 | 89.9 | 52.2 |
| All owners | 641.6 | 3.4 | 270.7 | 225.0 | 142.5 |
| Exotic | | | | | |
| National forest | -- | -- | -- | -- | -- |
| Other federal | -- | -- | -- | -- | -- |
| Indian | -- | -- | -- | -- | -- |
| State | -- | -- | -- | -- | -- |
| County and municipal | -- | -- | -- | -- | -- |
| Forest industry | -- | -- | -- | -- | -- |
| Farmer | -- | -- | -- | -- | -- |
| Miscellaneous private | 2.2 | -- | -- | -- | 2.2 |
| All owners | 2.2 | -- | -- | -- | 2.2 |
| Nonstocked | | | | | |
| National forest | -- | -- | -- | -- | -- |
| Other federal | 5.5 | -- | -- | -- | 5.5 |
| Indian | 3.8 | -- | -- | -- | 3.8 |
| State | 5.3 | -- | -- | -- | 5.3 |
| County and municipal | 16.3 | -- | -- | -- | 16.3 |
| Forest industry | 12.5 | -- | -- | -- | 12.5 |
| Farmer | 36.5 | -- | -- | -- | 36.5 |
| Miscellaneous private | 80.5 | -- | -- | -- | 80.5 |
| All owners | 160.4 | -- | -- | -- | 160.4 |
| All types | | | | | |
| National forest | 1,242.3 | 27.2 | 621.9 | 366.4 | 226.8 |
| Other federal | 176.2 | -- | 54.5 | 54.3 | 67.4 |
| Indian | 353.7 | 32.3 | 171.4 | 117.1 | 32.9 |
| State | 569.4 | 8.6 | 214.0 | 149.5 | 197.3 |
| County and municipal | 2,179.8 | 11.4 | 666.0 | 812.0 | 690.4 |
| Forest industry | 1,156.0 | 30.6 | 467.8 | 301.7 | 355.9 |
| Farmer | 3,513.7 | 51.2 | 1,662.6 | 1,002.3 | 797.6 |
| Miscellaneous private | 5,568.3 | 99.6 | 2,260.4 | 1,695.3 | 1,513.0 |
| All owners | 14,759.4 | 260.9 | 6,118.6 | 4,498.6 | 3,881.3 |

Table 13.--Area of timberland by distance from major wood-using center and operability class, Michigan, 1980

(In thousand acres)

| Wood-using center and distance (miles) | All classes | Operability class: I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
|---|---|---|---|---|---|
| Cornell-Stanley | | | | | |
| Less than 20 | 326.8 | -- | 124.5 | 89.4 | 112.9 |
| 20-50 | 1,763.9 | 25.5 | 627.5 | 641.9 | 469.0 |
| More than 50 | 12,668.7 | 235.4 | 5,366.6 | 3,767.3 | 3,299.4 |
| Durand | | | | | |
| Less than 20 | 261.4 | 2.8 | 131.5 | 59.3 | 67.8 |
| 20-50 | 772.9 | 10.3 | 393.1 | 215.1 | 154.4 |
| More than 50 | 13,725.1 | 247.8 | 5,594.0 | 4,224.2 | 3,659.1 |
| Green Bay | | | | | |
| Less than 20 | 126.6 | 1.8 | 37.4 | 63.4 | 24.0 |
| 20-50 | 792.6 | 20.5 | 328.0 | 272.0 | 172.1 |
| More than 50 | 13,840.2 | 238.6 | 5,753.2 | 4,163.2 | 3,685.2 |
| Hayward | | | | | |
| Less than 20 | 542.0 | 6.9 | 225.3 | 191.7 | 118.1 |
| 20-50 | 2,629.0 | 41.5 | 1,050.8 | 837.2 | 699.5 |
| More than 50 | 11,588.4 | 212.5 | 4,842.5 | 3,469.7 | 3,063.7 |
| Kaukauna | | | | | |
| Less than 20 | 96.2 | -- | 20.2 | 48.2 | 27.8 |
| 20-50 | 779.0 | 18.7 | 306.3 | 298.2 | 155.8 |
| More than 50 | 13,884.2 | 242.2 | 5,792.1 | 4,152.2 | 3,697.7 |
| Niagara-Peshtigo | | | | | |
| Less than 20 | 438.4 | 5.0 | 164.7 | 137.8 | 130.9 |
| 20-50 | 1,501.0 | 58.3 | 653.1 | 486.8 | 302.8 |
| More than 50 | 12,820.0 | 197.6 | 5,300.8 | 3,874.0 | 3,447.6 |
| Onalaska | | | | | |
| Less than 20 | 234.2 | -- | 131.4 | 71.0 | 31.8 |
| 20-50 | 1,128.1 | 13.6 | 556.8 | 292.3 | 265.4 |
| More than 50 | 13,397.1 | 247.3 | 5,430.4 | 4,135.3 | 3,584.1 |
| Park Falls | | | | | |
| Less than 20 | 577.0 | 10.1 | 224.6 | 155.9 | 186.4 |
| 20-50 | 2,572.7 | 34.8 | 1,117.2 | 758.3 | 662.4 |
| More than 50 | 11,609.7 | 216.0 | 4,776.8 | 3,584.4 | 3,032.5 |
| Rice Lake-Spooner | | | | | |
| Less than 20 | 368.6 | 3.7 | 167.7 | 125.1 | 72.1 |
| 20-50 | 2,235.0 | 28.3 | 904.5 | 713.8 | 588.4 |
| More than 50 | 12,155.8 | 228.9 | 5,046.4 | 3,659.7 | 3,220.8 |
| Shawano | | | | | |
| Less than 20 | 354.4 | 19.8 | 154.2 | 127.5 | 52.9 |
| 20-50 | 1,661.0 | 58.4 | 684.7 | 593.0 | 324.9 |
| More than 50 | 12,744.0 | 182.7 | 5,279.7 | 3,778.1 | 3,503.5 |
| Superior | | | | | |
| Less than 20 | 169.7 | 3.8 | 43.9 | 53.3 | 68.7 |
| 20-50 | 1,143.7 | 4.8 | 403.0 | 370.9 | 365.0 |
| More than 50 | 13,446.0 | 252.3 | 5,671.7 | 4,074.4 | 3,447.6 |
| Tomahawk | | | | | |
| Less than 20 | 553.0 | 3.7 | 179.5 | 163.8 | 206.0 |
| 20-50 | 2,305.3 | 31.6 | 920.5 | 665.6 | 687.6 |
| More than 50 | 11,901.1 | 225.6 | 5,018.6 | 3,669.2 | 2,987.7 |
| Wausau | | | | | |
| Less than 20 | 343.2 | 9.4 | 148.4 | 91.5 | 93.9 |
| 20-50 | 2,035.0 | 55.7 | 760.9 | 670.5 | 547.9 |
| More than 50 | 12,381.2 | 195.8 | 5,209.3 | 3,736.6 | 3,239.5 |
| Wisconsin Rapids | | | | | |
| Less than 20 | 299.5 | 2.3 | 78.4 | 85.3 | 133.5 |
| 20-50 | 1,748.6 | 32.3 | 655.8 | 521.5 | 539.0 |
| More than 50 | 12,711.3 | 226.3 | 5,384.4 | 3,891.8 | 3,208.8 |
| Closest wood-using center | | | | | |
| Less than 20 | 4,521.4 | 67.6 | 1,781.6 | 1,389.4 | 1,282.8 |
| 20-50 | 8,622.1 | 155.4 | 3,569.0 | 2,640.3 | 2,257.4 |
| More than 50 | 1,615.9 | 37.9 | 768.0 | 468.9 | 341.1 |

Table 14.--Growing-stock volume on timberland by operability class component and forest type, Wisconsin, 1983

(In thousand cubic feet)

| Operability class component | All types | Forest type: Jack pine | Red pine | White pine | Balsam fir | White spruce | Black spruce | Northern white-cedar | Tamarack |
|---|---|---|---|---|---|---|---|---|---|
| Stand area (acres) | | | | | | | | | |
| More than 60 | 5,451,076 | 166,179 | 153,834 | 66,367 | 75,193 | 45,083 | 8,100 | 132,645 | 21,146 |
| 10-60 | 7,688,624 | 197,442 | 358,637 | 182,431 | 234,159 | 32,086 | 67,501 | 272,900 | 69,916 |
| Less than 10 | 2,358,485 | 78,059 | 209,341 | 120,291 | 86,449 | 21,080 | 48,899 | 56,109 | 23,012 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |
| Growing-stock volume (cubic feet/acre) | | | | | | | | | |
| More than 1,000 | 11,764,926 | 280,772 | 686,816 | 326,850 | 242,274 | 90,975 | 59,957 | 364,607 | 40,493 |
| 400-1,000 | 3,222,509 | 141,314 | 29,887 | 40,142 | 135,975 | 5,946 | 41,461 | 92,693 | 58,082 |
| Less than 400 | 510,750 | 19,594 | 5,109 | 2,097 | 17,552 | 1,328 | 23,082 | 4,354 | 15,499 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |
| Sawtimber volume (board feet/acre) | | | | | | | | | |
| More than 2,500 | 8,589,858 | 152,031 | 434,707 | 339,402 | 205,215 | 68,898 | 41,386 | 225,386 | 12,431 |
| 700-2,500 | 4,476,394 | 186,238 | 98,350 | 14,415 | 144,233 | 27,009 | 34,916 | 164,267 | 38,169 |
| Less than 700 | 2,431,933 | 103,411 | 188,755 | 15,272 | 46,353 | 2,342 | 48,198 | 72,001 | 63,474 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |
| Percent cull trees (percent) | | | | | | | | | |
| Less than 20 | 12,204,603 | 382,729 | 695,826 | 326,319 | 360,125 | 95,420 | 114,736 | 375,928 | 106,984 |
| 20-50 | 2,714,556 | 51,611 | 21,852 | 31,073 | 34,231 | 1,876 | 7,809 | 82,055 | 6,313 |
| More than 50 | 579,026 | 7,340 | 4,134 | 11,697 | 1,445 | 953 | 1,955 | 3,671 | 777 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |
| Average d.b.h. of growing-stock trees (inches) | | | | | | | | | |
| More than 9 | 5,845,764 | 76,472 | 149,027 | 222,871 | 71,203 | 8,573 | 5,850 | 64,743 | 4,545 |
| 6-9 | 9,398,590 | 335,399 | 524,314 | 146,218 | 316,167 | 88,206 | 102,444 | 378,103 | 96,213 |
| Less than 6 | 253,831 | 29,809 | 48,471 | -- | 8,431 | 1,470 | 16,206 | 18,808 | 13,316 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |
| Average merchantable height of growing-stock trees (feet) | | | | | | | | | |
| More than 28 | 12,797,202 | 221,409 | 455,150 | 317,811 | 239,724 | 72,116 | 56,780 | 141,305 | 42,698 |
| 16-28 | 2,681,400 | 218,521 | 266,488 | 51,278 | 155,139 | 24,663 | 67,482 | 312,675 | 70,672 |
| Less than 16 | 19,583 | 1,750 | 174 | -- | 938 | 1,470 | 238 | 7,674 | 704 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |
| Distance to road (miles) | | | | | | | | | |
| Less than 1/4 | 7,484,081 | 306,394 | 554,775 | 225,276 | 139,616 | 66,407 | 41,507 | 198,268 | 38,278 |
| 1/4-3/4 | 6,706,844 | 125,931 | 126,754 | 139,011 | 199,630 | 25,725 | 67,886 | 217,180 | 67,451 |
| More than 3/4 | 1,307,260 | 9,355 | 40,283 | 4,802 | 56,555 | 6,117 | 15,107 | 46,206 | 8,345 |
| All classes | 15,498,185 | 441,680 | 721,812 | 369,089 | 395,801 | 98,249 | 124,500 | 461,654 | 114,074 |

(Table 14 continued on next page)

(Table 14 continued)

| Operability class component | Forest type: Oak-hickory | Elm-ash-soft maple | Maple-birch | Aspen | Paper birch | Exotic | Non-stocked |
|---|---|---|---|---|---|---|---|
| Stand area (acres) | | | | | | | |
| More than 60 | 1,096,863 | 244,519 | 2,260,532 | 977,814 | 197,214 | 556 | 5,031 |
| 10-60 | 1,556,369 | 622,320 | 2,233,708 | 1,415,444 | 439,413 | -- | 6,298 |
| Less than 10 | 323,270 | 294,142 | 551,074 | 448,870 | 92,616 | -- | 5,273 |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |
| Growing-stock volume (cubic feet/acre) | | | | | | | |
| More than 1,000 | 2,144,090 | 804,292 | 4,189,265 | 1,976,360 | 558,175 | -- | -- |
| 400-1,000 | 735,332 | 298,239 | 773,603 | 712,154 | 156,366 | -- | 1,315 |
| Less than 400 | 97,080 | 58,450 | 82,446 | 153,614 | 14,702 | 556 | 15,287 |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |
| Sawtimber volume (board feet/acre) | | | | | | | |
| More than 2,500 | 2,039,337 | 623,911 | 3,299,286 | 868,795 | 279,073 | -- | -- |
| 700-2,500 | 647,249 | 381,690 | 1,346,740 | 1,126,555 | 263,633 | -- | 2,930 |
| Less than 700 | 289,916 | 155,380 | 399,288 | 846,778 | 186,537 | 556 | 13,672 |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |
| Percent cull trees (percent) | | | | | | | |
| Less than 20 | 1,922,812 | 866,745 | 3,897,529 | 2,454,240 | 600,277 | -- | 4,933 |
| 20-50 | 818,447 | 249,265 | 978,813 | 319,208 | 108,041 | 556 | 3,406 |
| More than 50 | 235,243 | 44,971 | 168,972 | 68,680 | 20,925 | -- | 8,263 |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |
| Average d.b.h. of growing-stock trees (inches) | | | | | | | |
| More than 9 | 1,772,975 | 442,250 | 2,236,905 | 639,230 | 144,930 | -- | 6,190 |
| 6-9 | 1,188,157 | 701,993 | 2,782,366 | 2,150,874 | 577,724 | -- | 10,412 |
| Less than 6 | 15,370 | 16,738 | 26,043 | 52,024 | 6,589 | 556 | -- |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |
| Average merchantable height of growing-stock trees (feet) | | | | | | | |
| More than 28 | 2,663,277 | 906,660 | 4,580,979 | 2,455,932 | 632,501 | -- | 10,860 |
| 16-28 | 311,247 | 254,167 | 462,720 | 383,308 | 96,742 | 556 | 5,742 |
| Less than 16 | 1,978 | 154 | 1,615 | 2,888 | -- | -- | -- |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |
| Distance to road (miles) | | | | | | | |
| Less than 1/4 | 1,524,655 | 519,275 | 2,238,871 | 1,267,355 | 355,230 | 556 | 7,618 |
| 1/4-3/4 | 1,360,370 | 528,132 | 2,230,238 | 1,296,937 | 312,902 | -- | 8,697 |
| More than 3/4 | 91,477 | 113,574 | 576,205 | 277,836 | 61,111 | -- | 287 |
| All classes | 2,976,502 | 1,160,981 | 5,045,314 | 2,842,128 | 729,243 | 556 | 16,602 |

Table 15.--Growing-stock volume on timberland by forest type and operability class, Wisconsin, 1983

(In thousand cubic feet)

| Forest type | All classes | Operability class: I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
|---|---|---|---|---|---|
| Jack pine | 441,680 | -- | 256,889 | 140,740 | 44,051 |
| Red pine | 721,812 | 25,606 | 311,511 | 362,931 | 21,764 |
| White pine | 369,089 | 12,371 | 219,746 | 128,464 | 8,508 |
| Balsam fir | 395,801 | -- | 201,462 | 144,077 | 50,262 |
| White spruce | 98,249 | -- | 69,531 | 26,741 | 1,977 |
| Black spruce | 124,500 | -- | 25,657 | 64,459 | 34,384 |
| Northern white-cedar | 461,654 | 2,175 | 299,633 | 141,235 | 18,611 |
| Tamarack | 114,074 | -- | 31,408 | 54,755 | 27,911 |
| Oak-hickory | 2,976,502 | 143,637 | 1,947,003 | 742,792 | 143,070 |
| Elm-ash-soft maple | 1,160,981 | 22,376 | 594,578 | 449,279 | 94,748 |
| Maple-birch | 5,045,314 | 247,137 | 3,135,576 | 1,381,808 | 280,793 |
| Aspen | 2,842,128 | 40,516 | 1,352,143 | 1,069,847 | 379,622 |
| Paper birch | 729,243 | 4,990 | 406,702 | 255,328 | 62,223 |
| Exotic | 556 | -- | -- | -- | 556 |
| Nonstocked | 16,602 | -- | -- | -- | 16,602 |
| All types | 15,498,185 | 498,808 | 8,851,839 | 4,962,456 | 1,185,082 |

Table 16.--Growing-stock volume on timberland in operability class II (medium) by limiting factor and forest type, Wisconsin, 1983

(In thousand cubic feet)

| Limiting factor | All types | Forest type: Jack pine | Red pine | White pine | Balsam fir | White spruce | Black spruce |
|---|---|---|---|---|---|---|---|
| 1 | 760,550 | 17,915 | 44,952 | 67,512 | 6,072 | -- | -- |
| 2 | 17,342 | 2,045 | -- | -- | -- | -- | -- |
| 3 | 20,149 | -- | -- | -- | -- | -- | -- |
| 4 | 97,261 | -- | -- | -- | -- | -- | -- |
| 5 | 477,935 | 7,317 | 57,769 | 5,855 | 2,228 | 35,153 | -- |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 608,830 | 7,727 | -- | 23,826 | -- | -- | -- |
| 1 & 2 | 55,552 | 1,355 | -- | 1,799 | 6,173 | -- | 1,321 |
| 1 & 3 | 20,461 | -- | -- | -- | -- | -- | -- |
| 1 & 4 | 241,725 | 3,703 | 3,214 | 2,948 | -- | -- | -- |
| 1 & 5 | 685,419 | 28,731 | 75,527 | 35,167 | 13,819 | 3,870 | 5,906 |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 634,138 | 3,572 | 14,553 | 20,918 | 12,492 | -- | -- |
| 2 & 3 | 22,821 | -- | -- | -- | -- | -- | -- |
| 2 & 4 | 26,556 | 1,559 | -- | -- | -- | -- | -- |
| 2 & 5 | 15,760 | -- | -- | -- | 10,056 | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | 26,771 | -- | -- | -- | 1,393 | -- | -- |
| 3 & 4 | 5,404 | -- | -- | -- | -- | -- | -- |
| 3 & 5 | 238,801 | 2,547 | 13,231 | -- | -- | 2,265 | -- |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | 20,558 | -- | -- | -- | -- | -- | -- |
| 4 & 5 | 28,410 | -- | -- | -- | -- | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | 170,476 | 2,112 | -- | -- | -- | -- | -- |
| 5 & 6 | 37,618 | 2,382 | 6,017 | -- | 6,002 | -- | -- |
| 5 & 7 | 483,399 | 11,792 | 10,083 | 15,032 | 14,214 | 4,540 | -- |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | 59,133 | 933 | -- | -- | 3,881 | -- | -- |
| 1 & 2 & 4 | 61,950 | 1,432 | 677 | -- | -- | -- | -- |
| 1 & 2 & 5 | 12,108 | 5,558 | -- | -- | 1,823 | -- | -- |
| 1 & 2 & 6 | 1,589 | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | 57,429 | 1,172 | 2,931 | -- | 3,140 | -- | -- |
| 1 & 3 & 4 | 6,885 | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 5 | 394,848 | 13,600 | 17,291 | -- | 2,335 | -- | -- |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | 30,233 | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 5 | 81,413 | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | 219,974 | 3,666 | -- | 4,692 | -- | -- | -- |
| 1 & 5 & 6 | 109,831 | 4,171 | 15,195 | 21,274 | 4,625 | -- | -- |
| 1 & 5 & 7 | 508,558 | 2,041 | 9,777 | 7,873 | 21,291 | -- | 2,514 |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | 12,977 | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 5 | 24,134 | 2,881 | 1,713 | -- | -- | -- | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | 33,317 | -- | -- | 1,289 | 1,684 | -- | -- |
| 2 & 4 & 5 | 2,504 | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | 38,384 | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 6 | 4,931 | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 7 | 2,476 | -- | -- | -- | -- | 2,476 | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | 34,803 | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | 8,752 | -- | -- | -- | -- | -- | -- |
| 3 & 5 & 6 | 129,157 | 49,212 | -- | -- | -- | -- | 1,861 |
| 3 & 5 & 7 | 356,474 | 12,800 | 3,236 | -- | -- | -- | -- |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | 2,473 | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 7 | 55,292 | -- | -- | -- | 2,036 | -- | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | 62,288 | 3,455 | -- | -- | 3,819 | -- | -- |
| 4 or more | 1,843,990 | 63,211 | 35,345 | 11,561 | 84,379 | 21,227 | 14,055 |
| All factors | 8,851,839 | 256,889 | 311,511 | 219,746 | 201,462 | 69,531 | 25,657 |

(Table 16 continued on next page)

(Table 16 continued)

| Limiting factor | Northern white-cedar | Tamarack | Oak-hickory | Elm-ash-soft maple | Maple-birch | Aspen | Paper birch |
|---|---|---|---|---|---|---|---|
| | Forest type | | | | | | |
| 1 | -- | -- | 206,327 | 37,812 | 286,124 | 62,326 | 31,510 |
| 2 | -- | -- | 11,197 | 1,174 | 2,926 | -- | -- |
| 3 | -- | -- | 3,196 | -- | 4,987 | 11,966 | -- |
| 4 | -- | -- | 34,993 | 9,640 | 47,548 | 5,080 | -- |
| 5 | 12,884 | -- | 60,676 | 7,313 | 223,922 | 51,833 | 12,985 |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 12,079 | -- | 153,503 | 35,798 | 321,018 | 42,895 | 11,984 |
| 1 & 2 | 1,764 | -- | 32,964 | 1,455 | 1,540 | 4,631 | 2,550 |
| 1 & 3 | -- | -- | 6,923 | -- | 2,735 | 8,492 | 2,311 |
| 1 & 4 | -- | -- | 103,695 | 12,432 | 103,450 | 9,598 | 2,685 |
| 1 & 5 | 13,163 | 4,872 | 82,652 | 56,773 | 213,157 | 100,635 | 51,147 |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 14,563 | -- | 183,748 | 43,186 | 252,325 | 76,729 | 12,052 |
| 2 & 3 | -- | -- | 3,303 | 2,329 | 2,881 | 10,601 | 3,707 |
| 2 & 4 | -- | -- | 15,821 | 1,681 | 7,495 | -- | -- |
| 2 & 5 | -- | -- | 2,836 | -- | 2,868 | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | -- | -- | 7,911 | 1,480 | 7,879 | 5,723 | 2,385 |
| 3 & 4 | -- | -- | 5,404 | -- | -- | -- | -- |
| 3 & 5 | -- | -- | 28,874 | 12,630 | 84,893 | 76,339 | 18,022 |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | -- | -- | 2,750 | -- | 4,508 | 11,242 | 2,058 |
| 4 & 5 | -- | -- | 9,704 | 2,494 | 16,212 | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | 2,037 | -- | 79,382 | 10,134 | 66,940 | 9,871 | -- |
| 5 & 6 | 4,679 | -- | 11,231 | 2,149 | 5,158 | -- | -- |
| 5 & 7 | 5,276 | -- | 111,298 | 6,459 | 208,849 | 72,410 | 23,446 |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | -- | -- | 14,666 | 9,411 | 10,954 | 14,847 | 4,441 |
| 1 & 2 & 4 | -- | -- | 40,456 | 1,628 | 16,198 | -- | 1,559 |
| 1 & 2 & 5 | -- | -- | 4,727 | -- | -- | -- | -- |
| 1 & 2 & 6 | 1,589 | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | -- | -- | 26,013 | 6,313 | 10,807 | 7,053 | -- |
| 1 & 3 & 4 | -- | -- | 6,885 | -- | -- | -- | -- |
| 1 & 3 & 5 | -- | -- | 43,307 | 29,596 | 116,499 | 126,047 | 46,173 |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | -- | -- | 2,983 | 4,732 | 9,961 | 12,557 | -- |
| 1 & 4 & 5 | 12,758 | -- | 14,730 | 10,057 | 39,784 | 4,084 | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | 4,010 | -- | 86,339 | 15,111 | 86,857 | 10,039 | 9,260 |
| 1 & 5 & 6 | 21,277 | 3,212 | 14,155 | 15,736 | 2,218 | -- | 7,968 |
| 1 & 5 & 7 | 9,685 | 2,873 | 108,260 | 30,942 | 170,322 | 105,348 | 37,632 |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | -- | -- | 7,180 | 1,037 | 1,416 | 1,928 | 1,416 |
| 2 & 3 & 5 | -- | -- | 4,083 | 3,860 | 10,209 | 1,388 | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | -- | 970 | 7,501 | -- | 10,899 | 10,974 | -- |
| 2 & 4 & 5 | -- | -- | 2,504 | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | 1,327 | -- | 28,087 | 1,905 | 7,065 | -- | -- |
| 2 & 5 & 6 | -- | -- | 2,895 | 2,036 | -- | -- | -- |
| 2 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | -- | -- | 9,664 | -- | 17,639 | -- | 7,500 |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | -- | -- | 2,166 | -- | 1,944 | 4,642 | -- |
| 3 & 5 & 6 | 18,421 | -- | 11,159 | -- | 31,499 | 11,473 | 5,532 |
| 3 & 5 & 7 | 3,247 | 2,776 | 34,155 | 15,741 | 123,790 | 130,540 | 30,189 |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | -- | -- | -- | -- | 2,473 | -- | -- |
| 4 & 5 & 7 | -- | -- | 3,067 | -- | 37,950 | 12,239 | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | 8,717 | -- | 8,968 | 9,564 | 27,765 | -- | -- |
| 4 or more | 152,157 | 16,705 | 304,665 | 191,970 | 531,912 | 338,613 | 78,190 |
| All factors | 299,633 | 31,408 | 1,947,003 | 594,578 | 3,135,576 | 1,352,143 | 406,702 |

Table 17.--Growing-stock volume on timberland in operability class III (poor) by limiting factor and forest type, Wisconsin, 1983

(In thousand cubic feet)

| Limiting factor | All types | Forest type: Jack pine | Red pine | White pine | Balsam fir | White spruce | Black spruce |
|---|---|---|---|---|---|---|---|
| 1 | 1,630,151 | 50,764 | 138,694 | 97,968 | 69,003 | 19,306 | 33,325 |
| 2 | 26,346 | -- | -- | -- | -- | -- | 369 |
| 3 | 1,212,576 | 46,691 | 89,433 | 5,544 | 10,120 | -- | 13,994 |
| 4 | 299,350 | 3,910 | 3,780 | 6,748 | -- | -- | -- |
| 5 | 18,237 | 2,624 | 5,600 | -- | 2,076 | -- | 1,732 |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 965,243 | 5,971 | 32,928 | -- | 46,390 | 6,117 | 1,200 |
| 1 & 2 | 12,734 | 811 | -- | 647 | -- | -- | -- |
| 1 & 3 | 230,727 | 7,587 | 50,220 | 7,806 | -- | -- | 856 |
| 1 & 4 | 66,413 | 2,316 | -- | 4,698 | -- | -- | -- |
| 1 & 5 | 2,754 | -- | -- | -- | -- | -- | -- |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 82,076 | 1,516 | -- | 4,802 | 1,897 | -- | 7,707 |
| 2 & 3 | 37,731 | 1,496 | 480 | -- | 4,970 | -- | 1,000 |
| 2 & 4 | 18,300 | -- | -- | -- | -- | -- | -- |
| 2 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | 2,045 | -- | -- | -- | -- | -- | -- |
| 3 & 4 | 34,573 | -- | -- | -- | -- | -- | 765 |
| 3 & 5 | 80,045 | 12,464 | 28,338 | -- | 3,027 | -- | 2,452 |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | 131,163 | -- | 3,384 | -- | 3,519 | -- | -- |
| 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | 24,451 | -- | -- | -- | -- | -- | -- |
| 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | 13,366 | 824 | -- | -- | 713 | -- | 547 |
| 1 & 2 & 4 | 4,204 | -- | -- | -- | 486 | -- | -- |
| 1 & 2 & 5 | 901 | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 4 | 5,238 | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 5 | 14,165 | 1,364 | 9,095 | -- | -- | -- | -- |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | 4,683 | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 7 | 3,984 | -- | -- | -- | -- | -- | -- |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | 12,830 | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 5 | 5,414 | 522 | 625 | -- | -- | -- | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | 3,203 | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | 730 | -- | -- | -- | -- | -- | -- |
| 3 & 5 & 6 | 8,167 | 1,003 | -- | -- | 938 | -- | -- |
| 3 & 5 & 7 | 2,016 | -- | -- | -- | 938 | -- | -- |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 or more | 8,640 | 877 | 354 | 251 | -- | 1,318 | 512 |
| All factors | 4,962,456 | 140,740 | 362,931 | 128,464 | 144,077 | 26,741 | 64,459 |

(Table 17 continued on next page)

(Table 17 continued)

| Limiting factor | Northern white-cedar | Tamarack | Oak-hickory | Elm-ash-soft maple | Maple-birch | Aspen | Paper birch |
|---|---|---|---|---|---|---|---|
| | Forest type | | | | | | |
| 1 | 37,745 | 7,307 | 233,830 | 210,531 | 424,085 | 251,279 | 56,314 |
| 2 | -- | 480 | 9,266 | 3,246 | 3,576 | 8,919 | 490 |
| 3 | 37,908 | 25,869 | 183,562 | 61,517 | 211,236 | 421,084 | 105,618 |
| 4 | 805 | -- | 148,415 | 16,865 | 86,709 | 21,584 | 10,534 |
| 5 | -- | -- | 3,500 | -- | 1,754 | 951 | -- |
| 6 | -- | -- | -- | -- | -- | -- | -- |
| 7 | 40,399 | 1,474 | 60,159 | 80,321 | 505,959 | 150,561 | 33,764 |
| 1 & 2 | -- | 631 | 3,028 | 3,681 | 2,739 | 1,197 | -- |
| 1 & 3 | 5,753 | 5,206 | 18,543 | 9,210 | 26,295 | 87,920 | 11,331 |
| 1 & 4 | 1,185 | -- | 17,110 | 10,113 | 20,449 | 8,393 | 2,149 |
| 1 & 5 | -- | -- | -- | -- | 2,754 | -- | -- |
| 1 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 7 | 1,529 | 1,712 | 8,603 | 18,396 | 20,761 | 7,793 | 7,360 |
| 2 & 3 | -- | 1,525 | 4,201 | 5,370 | 7,777 | 7,908 | 3,004 |
| 2 & 4 | -- | -- | 11,047 | 1,603 | 4,213 | 1,437 | -- |
| 2 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 7 | -- | -- | 819 | 600 | -- | 626 | -- |
| 3 & 4 | -- | -- | 6,661 | 3,826 | 11,034 | 8,767 | 3,520 |
| 3 & 5 | 5,527 | 5,778 | 946 | 5,698 | 8,065 | 6,720 | 1,030 |
| 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 7 | 2,484 | 2,483 | 9,007 | 4,185 | 26,523 | 62,506 | 17,072 |
| 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 7 | -- | -- | 8,764 | -- | 7,380 | 6,923 | 1,384 |
| 5 & 6 | -- | -- | -- | - | -- | -- | -- |
| 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 3 | -- | -- | 1,413 | 6,318 | 2,465 | 406 | 680 |
| 1 & 2 & 4 | -- | -- | 2,181 | -- | 1,537 | -- | -- |
| 1 & 2 & 5 | -- | -- | -- | 901 | -- | -- | -- |
| 1 & 2 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 2 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 4 | 722 | -- | 923 | 915 | 850 | 1,828 | -- |
| 1 & 3 & 5 | -- | 1,513 | 1,214 | -- | -- | 979 | -- |
| 1 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 3 & 7 | -- | -- | -- | 1,176 | -- | 3,507 | -- |
| 1 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 1 & 5 & 7 | -- | -- | 1,875 | -- | -- | 2,109 | -- |
| 1 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 4 | -- | 777 | 7,080 | -- | 3,199 | 1,774 | -- |
| 2 & 3 & 5 | -- | -- | -- | 2,059 | 732 | 1,476 | -- |
| 2 & 3 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 3 & 7 | 648 | -- | -- | 652 | 980 | 923 | -- |
| 2 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 4 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 2 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 5 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 3 & 4 & 7 | -- | -- | -- | 730 | -- | -- | -- |
| 3 & 5 & 6 | 6,226 | -- | -- | -- | -- | -- | -- |
| 3 & 5 & 7 | -- | -- | -- | -- | -- | -- | 1,078 |
| 3 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 6 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 5 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 5 & 6 & 7 | -- | -- | -- | -- | -- | -- | -- |
| 4 or more | 304 | -- | 645 | 1,366 | 736 | 2,277 | -- |
| All factors | 141,235 | 54,755 | 742,792 | 449,279 | 1,381,808 | 1,069,847 | 255,328 |

Table 18.--Growing-stock volume on timberland by forest type, average growing-stock volume and operability class, Wisconsin, 1983

(In thousand cubic feet)

| Forest type and average growing-stock volume per acre (cu.ft. per acre) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Jack pine | | | | | |
| More than 1,000 | 280,772 | -- | 200,936 | 74,302 | 5,534 |
| 400-1,000 | 141,314 | -- | 55,953 | 61,908 | 23,453 |
| Less than 400 | 19,594 | -- | -- | 4,530 | 15,064 |
| All classes | 441,680 | -- | 256,889 | 140,740 | 44,051 |
| Red pine | | | | | |
| More than 1,000 | 686,816 | 25,606 | 306,190 | 352,548 | 2,472 |
| 400-1,000 | 29,887 | -- | 5,321 | 8,924 | 15,642 |
| Less than 400 | 5,109 | -- | -- | 1,459 | 3,650 |
| All classes | 721,812 | 25,606 | 311,511 | 362,931 | 21,764 |
| White pine | | | | | |
| More than 1,000 | 326,850 | 12,371 | 210,131 | 104,348 | -- |
| 400-1,000 | 40,142 | -- | 9,615 | 23,218 | 7,309 |
| Less than 400 | 2,097 | -- | -- | 898 | 1,199 |
| All classes | 369,089 | 12,371 | 219,746 | 128,464 | 8,508 |
| Balsam fir | | | | | |
| More than 1,000 | 242,274 | -- | 131,087 | 105,452 | 5,735 |
| 400-1,000 | 135,975 | -- | 70,375 | 32,456 | 33,144 |
| Less than 400 | 17,552 | -- | -- | 6,169 | 11,383 |
| All classes | 395,801 | -- | 201,462 | 144,077 | 50,262 |
| White spruce | | | | | |
| More than 1,000 | 90,975 | -- | 67,055 | 23,920 | -- |
| 400-1,000 | 5,946 | -- | 2,476 | 2,821 | 649 |
| Less than 400 | 1,328 | -- | -- | -- | 1,328 |
| All classes | 98,249 | -- | 69,531 | 26,741 | 1,977 |
| Black spruce | | | | | |
| More than 1,000 | 59,957 | -- | 16,541 | 43,416 | -- |
| 400-1,000 | 41,461 | -- | 9,116 | 18,615 | 13,730 |
| Less than 400 | 23,082 | -- | -- | 2,428 | 20,654 |
| All classes | 124,500 | -- | 25,657 | 64,459 | 34,384 |
| Northern white-cedar | | | | | |
| More than 1,000 | 364,607 | 2,175 | 249,377 | 113,055 | -- |
| 400-1,000 | 92,693 | -- | 50,256 | 27,228 | 15,209 |
| Less than 400 | 4,354 | -- | -- | 952 | 3,402 |
| All classes | 461,654 | 2,175 | 299,633 | 141,235 | 18,611 |
| Tamarack | | | | | |
| More than 1,000 | 40,493 | -- | 19,979 | 18,474 | 2,040 |
| 400-1,000 | 58,082 | -- | 11,429 | 32,868 | 13,785 |
| Less than 400 | 15,499 | -- | -- | 3,413 | 12,086 |
| All classes | 114,074 | -- | 31,408 | 54,755 | 27,911 |

(Table 18 continued on next page)

(Table 18 continued)

| Forest type and average growing-stock volume per acre (cu.ft. per acre) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Oak-hickory | | | | | |
| More than 1,000 | 2,144,090 | 143,637 | 1,520,870 | 469,232 | 10,351 |
| 400-1,000 | 735,332 | -- | 426,133 | 233,880 | 75,319 |
| Less than 400 | 97,080 | -- | -- | 39,680 | 57,400 |
| All classes | 2,976,502 | 143,637 | 1,947,003 | 742,792 | 143,070 |
| Elm-ash-soft maple | | | | | |
| More than 1,000 | 804,292 | 22,376 | 478,841 | 293,233 | 9,842 |
| 400-1,000 | 298,239 | -- | 115,737 | 130,250 | 52,252 |
| Less than 400 | 58,450 | -- | -- | 25,796 | 32,654 |
| All classes | 1,160,981 | 22,376 | 594,578 | 449,279 | 94,748 |
| Maple-birch | | | | | |
| More than 1,000 | 4,189,265 | 247,137 | 2,849,256 | 1,053,940 | 38,932 |
| 400-1,000 | 773,603 | -- | 286,320 | 299,914 | 187,369 |
| Less than 400 | 82,446 | -- | -- | 27,954 | 54,492 |
| All classes | 5,045,314 | 247,137 | 3,135,576 | 1,381,808 | 280,793 |
| Aspen | | | | | |
| More than 1,000 | 1,976,360 | 40,516 | 1,156,186 | 722,110 | 57,548 |
| 400-1,000 | 712,154 | -- | 195,957 | 320,794 | 195,403 |
| Less than 400 | 153,614 | -- | -- | 26,943 | 126,671 |
| All classes | 2,842,128 | 40,516 | 1,352,143 | 1,069,847 | 379,622 |
| Paper birch | | | | | |
| More than 1,000 | 558,175 | 4,990 | 360,418 | 180,551 | 12,216 |
| 400-1,000 | 156,366 | -- | 46,284 | 70,603 | 39,479 |
| Less than 400 | 14,702 | -- | -- | 4,174 | 10,528 |
| All classes | 729,243 | 4,990 | 406,702 | 255,328 | 62,223 |
| Exotic | | | | | |
| More than 1,000 | -- | -- | -- | -- | -- |
| 400-1,000 | -- | -- | -- | -- | -- |
| Less than 400 | 556 | -- | -- | -- | 556 |
| All classes | 556 | -- | -- | -- | 556 |
| Nonstocked | | | | | |
| More than 1,000 | -- | -- | -- | -- | -- |
| 400-1,000 | 1,315 | -- | -- | -- | 1,315 |
| Less than 400 | 15,287 | -- | -- | -- | 15,287 |
| All classes | 16,602 | -- | -- | -- | 16,602 |
| All types | | | | | |
| More than 1,000 | 11,764,926 | 498,808 | 7,566,867 | 3,554,581 | 144,670 |
| 400-1,000 | 3,222,509 | -- | 1,284,972 | 1,263,479 | 674,058 |
| Less than 400 | 510,750 | -- | -- | 144,396 | 366,354 |
| All classes | 15,498,185 | 498,808 | 8,851,839 | 4,962,456 | 1,185,082 |

Table 19.--Growing-stock volume on timberland by forest type, stand-age class and operability class, Wisconsin, 1983

(In thousand cubic feet)

| Forest type and stand-age class (years) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Jack pine | | | | | |
| less than 21 | 30,055 | -- | -- | 1,733 | 28,322 |
| 21-40 | 154,409 | -- | 55,019 | 83,661 | 15,729 |
| 41-60 | 230,089 | -- | 178,263 | 51,826 | -- |
| 61-80 | 24,229 | -- | 20,709 | 3,520 | -- |
| 81-100 | 2,898 | -- | 2,898 | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 441,680 | -- | 256,889 | 140,740 | 44,051 |
| Red pine | | | | | |
| less than 21 | 74,645 | -- | -- | 54,162 | 20,483 |
| 21-40 | 401,996 | 2,928 | 200,925 | 196,862 | 1,281 |
| 41-60 | 159,224 | 13,972 | 72,336 | 72,916 | -- |
| 61-80 | 34,089 | 3,116 | 22,649 | 8,324 | -- |
| 81-100 | 43,311 | 5,590 | 10,407 | 27,314 | -- |
| 101-120 | 8,547 | -- | 5,194 | 3,353 | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 721,812 | 25,606 | 311,511 | 362,931 | 21,764 |
| White pine | | | | | |
| less than 21 | 16,213 | -- | -- | 7,705 | 8,508 |
| 21-40 | 31,711 | -- | 11,835 | 19,876 | -- |
| 41-60 | 69,484 | -- | 36,896 | 32,588 | -- |
| 61-80 | 114,366 | -- | 84,428 | 29,938 | -- |
| 81-100 | 58,178 | -- | 27,596 | 30,582 | -- |
| 101-120 | 23,443 | 4,135 | 11,533 | 7,775 | -- |
| More than 120 | 55,694 | 8,236 | 47,458 | -- | -- |
| All ages | 369,089 | 12,371 | 219,746 | 128,464 | 8,508 |
| Balsam fir | | | | | |
| less than 21 | 34,563 | -- | -- | -- | 34,563 |
| 21-40 | 59,948 | -- | 27,245 | 18,171 | 14,532 |
| 41-60 | 181,921 | -- | 106,056 | 74,698 | 1,167 |
| 61-80 | 79,471 | -- | 44,247 | 35,224 | -- |
| 81-100 | 19,404 | -- | 13,860 | 5,544 | -- |
| 101-120 | 12,716 | -- | 5,779 | 6,937 | -- |
| More than 120 | 7,778 | -- | 4,275 | 3,503 | -- |
| All ages | 395,801 | -- | 201,462 | 144,077 | 50,262 |
| White spruce | | | | | |
| less than 21 | 5,061 | -- | 2,265 | 1,318 | 1,478 |
| 21-40 | 60,041 | -- | 56,978 | 2,564 | 499 |
| 41-60 | 27,030 | -- | 10,288 | 16,742 | -- |
| 61-80 | 6,117 | -- | -- | 6,117 | -- |
| 81-100 | -- | -- | -- | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 98,249 | -- | 69,531 | 26,741 | 1,977 |

(Table 19 continued on next page)

(Table 19 continued)

| Forest type and stand-age class (years) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Black spruce | | | | | |
| less than 21 | 12,443 | -- | -- | -- | 12,443 |
| 21-40 | 24,287 | -- | 1,213 | 3,267 | 19,807 |
| 41-60 | 24,140 | -- | 4,899 | 17,107 | 2,134 |
| 61-80 | 48,193 | -- | 9,361 | 38,832 | -- |
| 81-100 | 15,068 | -- | 10,184 | 4,884 | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | 369 | -- | -- | 369 | -- |
| All ages | 124,500 | -- | 25,657 | 64,459 | 34,384 |
| Northern white-cedar | | | | | |
| less than 21 | 12,058 | -- | 3,247 | 955 | 7,856 |
| 21-40 | 15,317 | -- | -- | 6,639 | 8,678 |
| 41-60 | 97,138 | -- | 72,432 | 22,629 | 2,077 |
| 61-80 | 92,824 | -- | 52,454 | 40,370 | -- |
| 81-100 | 120,669 | -- | 83,797 | 36,872 | -- |
| 101-120 | 40,991 | 2,175 | 27,527 | 11,289 | -- |
| More than 120 | 82,657 | -- | 60,176 | 22,481 | -- |
| All ages | 461,654 | 2,175 | 299,633 | 141,235 | 18,611 |
| Tamarack | | | | | |
| less than 21 | 15,982 | -- | -- | -- | 15,982 |
| 21-40 | 17,403 | -- | -- | 5,474 | 11,929 |
| 41-60 | 32,592 | -- | 6,085 | 26,507 | -- |
| 61-80 | 32,939 | -- | 19,808 | 13,131 | -- |
| 81-100 | 9,749 | -- | 5,515 | 4,234 | -- |
| 101-120 | 2,957 | -- | -- | 2,957 | -- |
| More than 120 | 2,452 | -- | -- | 2,452 | -- |
| All ages | 114,074 | -- | 31,408 | 54,755 | 27,911 |
| Oak-hickory | | | | | |
| less than 21 | 131,082 | -- | 2,034 | 1,214 | 127,834 |
| 21-40 | 157,776 | -- | 78,434 | 64,106 | 15,236 |
| 41-60 | 947,909 | 41,534 | 610,764 | 295,611 | -- |
| 61-80 | 670,494 | 42,442 | 495,108 | 132,944 | -- |
| 81-100 | 544,726 | 31,112 | 388,441 | 125,173 | -- |
| 101-120 | 259,977 | 12,417 | 201,190 | 46,370 | -- |
| More than 120 | 264,538 | 16,132 | 171,032 | 77,374 | -- |
| All ages | 2,976,502 | 143,637 | 1,947,003 | 742,792 | 143,070 |
| Elm-ash-soft maple | | | | | |
| less than 21 | 76,358 | -- | -- | 4,971 | 71,387 |
| 21-40 | 164,940 | -- | 74,225 | 68,353 | 22,362 |
| 41-60 | 285,094 | 2,294 | 131,533 | 150,268 | 999 |
| 61-80 | 326,649 | 12,923 | 195,159 | 118,567 | -- |
| 81-100 | 194,125 | 2,331 | 112,270 | 79,524 | -- |
| 101-120 | 64,116 | 4,828 | 47,796 | 11,492 | -- |
| More than 120 | 49,699 | -- | 33,595 | 16,104 | -- |
| All ages | 1,160,981 | 22,376 | 594,578 | 449,279 | 94,748 |

(Table 19 continued on next page)

(Table 19 continued)

| Forest type and stand-age class (years) | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Maple-birch | | | | | |
| less than 21 | 220,656 | -- | 4,297 | 4,713 | 211,646 |
| 21-40 | 460,473 | 10,094 | 205,175 | 177,813 | 67,391 |
| 41-60 | 1,776,795 | 29,614 | 1,232,018 | 513,407 | 1,756 |
| 61-80 | 1,112,518 | 59,507 | 790,005 | 263,006 | -- |
| 81-100 | 684,199 | 53,836 | 454,787 | 175,576 | -- |
| 101-120 | 334,786 | 33,175 | 189,647 | 111,964 | -- |
| More than 120 | 455,887 | 60,911 | 259,647 | 135,329 | -- |
| All ages | 5,045,314 | 247,137 | 3,135,576 | 1,381,808 | 280,793 |
| Aspen | | | | | |
| less than 21 | 315,690 | -- | 5,736 | 7,547 | 302,407 |
| 21-40 | 676,184 | -- | 264,608 | 334,361 | 77,215 |
| 41-60 | 1,480,587 | 21,980 | 818,414 | 640,193 | -- |
| 61-80 | 305,301 | 18,536 | 213,555 | 73,210 | -- |
| 81-100 | 64,366 | -- | 49,830 | 14,536 | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 2,842,128 | 40,516 | 1,352,143 | 1,069,847 | 379,622 |
| Paper birch | | | | | |
| less than 21 | 45,064 | -- | -- | -- | 45,064 |
| 21-40 | 154,193 | -- | 61,419 | 75,875 | 16,899 |
| 41-60 | 376,857 | 4,275 | 241,443 | 130,879 | 260 |
| 61-80 | 147,725 | -- | 102,281 | 45,444 | -- |
| 81-100 | 2,754 | 715 | -- | 2,039 | -- |
| 101-120 | 2,650 | -- | 1,559 | 1,091 | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 729,243 | 4,990 | 406,702 | 255,328 | 62,223 |
| Exotic | | | | | |
| less than 21 | 556 | -- | -- | -- | 556 |
| 21-40 | -- | -- | -- | -- | -- |
| 41-60 | -- | -- | -- | -- | -- |
| 61-80 | -- | -- | -- | -- | -- |
| 81-100 | -- | -- | -- | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 556 | -- | -- | -- | 556 |
| Nonstocked | | | | | |
| less than 21 | 16,602 | -- | -- | -- | 16,602 |
| 21-40 | -- | -- | -- | -- | -- |
| 41-60 | -- | -- | -- | -- | -- |
| 61-80 | -- | -- | -- | -- | -- |
| 81-100 | -- | -- | -- | -- | -- |
| 101-120 | -- | -- | -- | -- | -- |
| More than 120 | -- | -- | -- | -- | -- |
| All ages | 16,602 | -- | -- | -- | 16,602 |
| All types | | | | | |
| less than 21 | 1,007,028 | -- | 17,579 | 84,318 | 905,131 |
| 21-40 | 2,378,678 | 13,022 | 1,037,076 | 1,057,022 | 271,558 |
| 41-60 | 5,688,860 | 113,669 | 3,521,427 | 2,045,371 | 8,393 |
| 61-80 | 2,994,915 | 136,524 | 2,049,764 | 808,627 | -- |
| 81-100 | 1,759,447 | 93,584 | 1,159,585 | 506,278 | -- |
| 101-120 | 750,183 | 56,730 | 490,225 | 203,228 | -- |
| More than 120 | 919,074 | 85,279 | 576,183 | 257,612 | -- |
| All ages | 15,498,185 | 498,808 | 8,851,839 | 4,962,456 | 1,185,082 |

Table 20.--Growing-stock volume on timberland by forest type, ownership class and operability class, Wisconsin, 1983

(In thousand cubic feet)

| Forest type and ownership class | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Jack Pine | | | | | |
| National forest | 69,663 | -- | 68,699 | 873 | 91 |
| Other federal | 16,783 | -- | 15,160 | 970 | 653 |
| Indian | 8,727 | -- | 7,673 | 1,054 | -- |
| State | 22,772 | -- | 8,455 | 8,839 | 5,478 |
| County and municipal | 97,619 | -- | 46,826 | 40,000 | 10,793 |
| Forest industry | 48,622 | -- | 20,521 | 22,231 | 5,870 |
| Farmer | 44,677 | -- | 23,597 | 18,455 | 2,625 |
| Miscellaneous private | 132,817 | -- | 65,958 | 48,318 | 18,541 |
| All owners | 441,680 | -- | 256,889 | 140,740 | 44,051 |
| Red pine | | | | | |
| National forest | 149,956 | 17,088 | 79,247 | 52,102 | 1,519 |
| Other federal | 3,917 | -- | 3,917 | -- | -- |
| Indian | 17,411 | -- | 17,411 | -- | -- |
| State | 50,536 | -- | 33,017 | 16,598 | 921 |
| County and municipal | 113,815 | 2,928 | 48,694 | 55,755 | 6,438 |
| Forest industry | 41,967 | -- | 32,019 | 7,494 | 2,454 |
| Farmer | 80,664 | -- | 27,783 | 51,876 | 1,005 |
| Miscellaneous private | 263,546 | 5,590 | 69,423 | 179,106 | 9,427 |
| All owners | 721,812 | 25,606 | 311,511 | 362,931 | 21,764 |
| White pine | | | | | |
| National forest | 27,378 | -- | 27,378 | -- | -- |
| Other federal | 4,715 | -- | 4,715 | -- | -- |
| Indian | 56,268 | 8,236 | 41,644 | 6,388 | -- |
| State | 13,194 | -- | 10,645 | 2,268 | 281 |
| County and municipal | 38,365 | -- | 15,915 | 21,060 | 1,390 |
| Forest industry | 28,036 | -- | 19,767 | 5,024 | 3,245 |
| Farmer | 86,943 | -- | 40,059 | 44,415 | 2,469 |
| Miscellaneous private | 114,190 | 4,135 | 59,623 | 49,309 | 1,123 |
| All owners | 369,089 | 12,371 | 219,746 | 128,464 | 8,508 |
| Balsam fir | | | | | |
| National forest | 52,985 | -- | 26,750 | 23,649 | 2,586 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 5,942 | -- | -- | 5,942 | -- |
| State | 20,980 | -- | 11,676 | 6,674 | 2,630 |
| County and municipal | 80,737 | -- | 32,592 | 40,167 | 7,978 |
| Forest industry | 35,268 | -- | 26,700 | 5,118 | 3,450 |
| Farmer | 31,383 | -- | 9,092 | 11,313 | 10,978 |
| Miscellaneous private | 168,506 | -- | 94,652 | 51,214 | 22,640 |
| All owners | 395,801 | -- | 201,462 | 144,077 | 50,262 |
| White spruce | | | | | |
| National forest | 71,776 | -- | 55,584 | 15,239 | 953 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | -- | -- | -- | -- | -- |
| State | -- | -- | -- | -- | -- |
| County and municipal | 373 | -- | -- | -- | 373 |
| Forest industry | 8,881 | -- | 2,265 | 6,117 | 499 |
| Farmer | -- | -- | -- | -- | -- |
| Miscellaneous private | 17,219 | -- | 11,682 | 5,385 | 152 |
| All owners | 98,249 | -- | 69,531 | 26,741 | 1,977 |

(Table 20 continued on next page)

(Table 20 continued)

| Forest type and ownership class | All classes | Operability class | | | |
|---|---|---|---|---|---|
| | | I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
| Black spruce | | | | | |
| National forest | 31,636 | -- | 1,086 | 25,758 | 4,792 |
| Other federal | 534 | -- | -- | -- | 534 |
| Indian | 4,884 | -- | -- | 4,884 | -- |
| State | 12,707 | -- | 4,345 | 6,150 | 2,212 |
| County and municipal | 19,411 | -- | -- | 13,520 | 5,891 |
| Forest industry | 19,294 | -- | 10,091 | 4,190 | 5,013 |
| Farmer | 4,872 | -- | -- | 780 | 4,092 |
| Miscellaneous private | 31,162 | -- | 10,135 | 9,177 | 11,850 |
| All owners | 124,500 | -- | 25,657 | 64,459 | 34,384 |
| Northern white-cedar | | | | | |
| National forest | 78,929 | -- | 59,284 | 18,494 | 1,151 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 37,201 | -- | 32,333 | 3,722 | 1,146 |
| State | 19,232 | 2,175 | 12,326 | 4,731 | -- |
| County and municipal | 50,195 | -- | 35,543 | 12,491 | 2,161 |
| Forest industry | 51,737 | -- | 30,930 | 20,100 | 707 |
| Farmer | 76,199 | -- | 55,511 | 12,860 | 7,828 |
| Miscellaneous private | 148,161 | -- | 73,706 | 68,837 | 5,618 |
| All owners | 461,654 | 2,175 | 299,633 | 141,235 | 18,611 |
| Tamarack | | | | | |
| National forest | 14,561 | -- | 1,784 | 12,143 | 634 |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 2,040 | -- | -- | -- | 2,040 |
| State | 4,911 | -- | 1,168 | 2,676 | 1,067 |
| County and municipal | 7,149 | -- | -- | 4,749 | 2,400 |
| Forest industry | 7,533 | -- | 1,121 | 4,554 | 1,858 |
| Farmer | 18,845 | -- | 2,059 | 12,496 | 4,290 |
| Miscellaneous private | 59,035 | -- | 25,276 | 18,137 | 15,622 |
| All owners | 114,074 | -- | 31,408 | 54,755 | 27,911 |
| Oak-hickory | | | | | |
| National forest | 82,381 | -- | 44,445 | 37,832 | 104 |
| Other federal | 34,204 | -- | 26,140 | 5,558 | 2,506 |
| Indian | 43,636 | 9,355 | 24,045 | 9,111 | 1,125 |
| State | 68,854 | 14,423 | 40,444 | 12,107 | 1,880 |
| County and municipal | 198,057 | 3,264 | 73,362 | 103,881 | 17,550 |
| Forest industry | 62,462 | 6,110 | 37,017 | 9,484 | 9,851 |
| Farmer | 1,397,144 | 54,979 | 1,004,535 | 291,559 | 46,071 |
| Miscellaneous private | 1,089,764 | 55,506 | 697,015 | 273,260 | 63,983 |
| All owners | 2,976,502 | 143,637 | 1,947,003 | 742,792 | 143,070 |
| Elm-ash-soft maple | | | | | |
| National forest | 27,597 | -- | 25,581 | 1,176 | 840 |
| Other federal | 36,861 | -- | 15,790 | 18,856 | 2,215 |
| Indian | 20,652 | -- | 14,571 | 4,915 | 1,166 |
| State | 56,878 | -- | 35,012 | 16,184 | 5,682 |
| County and municipal | 181,549 | 5,465 | 82,074 | 82,127 | 11,883 |
| Forest industry | 93,484 | -- | 56,242 | 32,319 | 4,923 |
| Farmer | 321,758 | 5,545 | 155,912 | 140,884 | 19,417 |
| Miscellaneous private | 422,202 | 11,366 | 209,396 | 152,818 | 48,622 |
| All owners | 1,160,981 | 22,376 | 594,578 | 449,279 | 94,748 |

(Table 20 continued on next page)

(Table 20 continued)

| Forest type and ownership class | All classes | Operability class: I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
|---|---|---|---|---|---|
| Maple-birch | | | | | |
| National forest | 643,471 | 32,638 | 435,211 | 173,642 | 1,980 |
| Other federal | 7,173 | -- | -- | 6,265 | 908 |
| Indian | 338,556 | 60,844 | 165,252 | 110,545 | 1,915 |
| State | 124,530 | -- | 76,494 | 38,874 | 9,162 |
| County and municipal | 596,327 | 9,848 | 337,066 | 210,050 | 39,363 |
| Forest industry | 617,769 | 56,616 | 353,376 | 184,992 | 22,785 |
| Farmer | 1,021,034 | 18,438 | 624,678 | 277,440 | 100,478 |
| Miscellaneous private | 1,696,454 | 68,753 | 1,143,499 | 380,000 | 104,202 |
| All owners | 5,045,314 | 247,137 | 3,135,576 | 1,381,808 | 280,793 |
| Aspen | | | | | |
| National forest | 253,773 | -- | 149,668 | 71,495 | 32,610 |
| Other federal | 27,535 | -- | 1,952 | 21,504 | 4,079 |
| Indian | 87,957 | -- | 41,703 | 39,525 | 6,729 |
| State | 105,774 | -- | 51,288 | 38,159 | 16,327 |
| County and municipal | 573,687 | 1,966 | 226,076 | 254,273 | 91,372 |
| Forest industry | 170,076 | -- | 86,378 | 53,407 | 30,291 |
| Farmer | 434,516 | 5,030 | 228,047 | 154,946 | 46,493 |
| Miscellaneous private | 1,188,810 | 33,520 | 567,031 | 436,538 | 151,721 |
| All owners | 2,842,128 | 40,516 | 1,352,143 | 1,069,847 | 379,622 |
| Paper birch | | | | | |
| National forest | 42,168 | 2,722 | 17,012 | 20,044 | 2,390 |
| Other federal | 6,091 | -- | 2,653 | 1,384 | 2,054 |
| Indian | 10,006 | -- | 6,081 | 3,925 | -- |
| State | 39,919 | -- | 28,270 | 10,365 | 1,284 |
| County and municipal | 120,543 | -- | 49,489 | 63,887 | 7,167 |
| Forest industry | 52,532 | -- | 32,794 | 18,455 | 1,283 |
| Farmer | 135,845 | -- | 80,488 | 32,754 | 22,603 |
| Miscellaneous private | 322,139 | 2,268 | 189,915 | 104,514 | 25,442 |
| All owners | 729,243 | 4,990 | 406,702 | 255,328 | 62,223 |
| Exotic | | | | | |
| National forest | -- | -- | -- | -- | -- |
| Other federal | -- | -- | -- | -- | -- |
| Indian | -- | -- | -- | -- | -- |
| State | -- | -- | -- | -- | -- |
| County and municipal | -- | -- | -- | -- | -- |
| Forest industry | -- | -- | -- | -- | -- |
| Farmer | -- | -- | -- | -- | -- |
| Miscellaneous private | 556 | -- | -- | -- | 556 |
| All owners | 556 | -- | -- | -- | 556 |
| Nonstocked | | | | | |
| National forest | -- | -- | -- | -- | -- |
| Other federal | -- | -- | -- | -- | -- |
| Indian | 479 | -- | -- | -- | 479 |
| State | 382 | -- | -- | -- | 382 |
| County and municipal | 656 | -- | -- | -- | 656 |
| Forest industry | 1,732 | -- | -- | -- | 1,732 |
| Farmer | 4,862 | -- | -- | -- | 4,862 |
| Miscellaneous private | 8,491 | -- | -- | -- | 8,491 |
| All owners | 16,602 | -- | -- | -- | 16,602 |
| All types | | | | | |
| National forest | 1,546,274 | 52,448 | 991,729 | 452,447 | 49,650 |
| Other federal | 137,813 | -- | 70,327 | 54,537 | 12,949 |
| Indian | 633,759 | 78,435 | 350,713 | 190,011 | 14,600 |
| State | 540,669 | 16,598 | 313,140 | 163,625 | 47,306 |
| County and municipal | 2,078,483 | 23,471 | 947,637 | 901,960 | 205,415 |
| Forest industry | 1,239,393 | 62,726 | 709,221 | 373,485 | 93,961 |
| Farmer | 3,658,742 | 83,992 | 2,251,761 | 1,049,778 | 273,211 |
| Miscellaneous private | 5,663,052 | 181,138 | 3,217,311 | 1,776,613 | 487,990 |
| All owners | 15,498,185 | 498,808 | 8,851,839 | 4,962,456 | 1,185,082 |

Table 21.--Growing-stock volume on timberland by distance from major wood-using center and operability class, Wisconsin, 1980

(In thousand cubic feet)

| Wood-using center and distance (miles) | All classes | Operability class: I - Good | II - Medium | III - Poor | IV - Sapling-seedling and nonstocked |
|---|---|---|---|---|---|
| Cornell-Stanley | | | | | |
| Less than 20 | 314,105 | -- | 181,747 | 95,866 | 36,492 |
| 20-50 | 1,735,317 | 42,412 | 913,485 | 642,609 | 136,811 |
| More than 50 | 13,448,763 | 456,396 | 7,756,607 | 4,223,981 | 1,011,779 |
| Durand | | | | | |
| Less than 20 | 253,598 | 5,817 | 181,152 | 52,202 | 14,427 |
| 20-50 | 797,842 | 14,344 | 524,208 | 211,346 | 47,944 |
| More than 50 | 14,446,745 | 478,647 | 8,146,479 | 4,698,908 | 1,122,711 |
| Green Bay | | | | | |
| Less than 20 | 141,908 | 2,066 | 60,183 | 74,979 | 4,680 |
| 20-50 | 966,284 | 45,898 | 510,500 | 348,971 | 60,915 |
| More than 50 | 14,389,993 | 450,844 | 8,281,156 | 4,538,506 | 1,119,487 |
| Hayward | | | | | |
| Less than 20 | 593,495 | 10,636 | 341,568 | 200,191 | 41,100 |
| 20-50 | 2,696,726 | 80,360 | 1,526,086 | 888,034 | 202,246 |
| More than 50 | 12,207,964 | 407,812 | 6,984,185 | 3,874,231 | 941,736 |
| Kaukauna | | | | | |
| Less than 20 | 89,270 | -- | 33,305 | 48,451 | 7,514 |
| 20-50 | 947,254 | 40,993 | 481,816 | 379,065 | 45,380 |
| More than 50 | 14,461,661 | 457,815 | 8,336,718 | 4,534,940 | 1,132,188 |
| Niagara-Peshtigo | | | | | |
| Less than 20 | 449,499 | 7,129 | 233,895 | 157,967 | 50,508 |
| 20-50 | 1,923,192 | 119,878 | 1,054,398 | 643,497 | 105,419 |
| More than 50 | 13,125,494 | 371,801 | 7,563,546 | 4,160,992 | 1,029,155 |
| Onalaska | | | | | |
| Less than 20 | 260,064 | -- | 178,975 | 67,855 | 13,234 |
| 20-50 | 1,101,817 | 18,620 | 727,471 | 285,770 | 69,956 |
| More than 50 | 14,136,304 | 480,188 | 7,945,393 | 4,608,831 | 1,101,892 |
| Park Falls | | | | | |
| Less than 20 | 607,602 | 23,073 | 338,281 | 188,459 | 57,789 |
| 20-50 | 2,785,534 | 64,478 | 1,716,419 | 819,418 | 185,219 |
| More than 50 | 12,105,049 | 411,257 | 6,797,139 | 3,954,579 | 942,074 |
| Rice Lake-Spooner | | | | | |
| Less than 20 | 423,461 | 5,532 | 255,790 | 145,024 | 17,115 |
| 20-50 | 2,210,759 | 53,920 | 1,278,099 | 702,628 | 176,112 |
| More than 50 | 12,863,965 | 439,356 | 7,317,950 | 4,114,804 | 991,855 |
| Shawano | | | | | |
| Less than 20 | 517,951 | 50,629 | 288,040 | 166,079 | 13,203 |
| 20-50 | 2,093,041 | 118,043 | 1,069,296 | 787,946 | 117,756 |
| More than 50 | 12,887,193 | 330,136 | 7,494,503 | 4,008,431 | 1,054,123 |
| Superior | | | | | |
| Less than 20 | 139,597 | 9,035 | 52,456 | 56,217 | 21,889 |
| 20-50 | 1,086,305 | 10,332 | 577,547 | 395,536 | 102,890 |
| More than 50 | 14,272,283 | 479,441 | 8,221,836 | 4,510,703 | 1,060,303 |
| Tomahawk | | | | | |
| Less than 20 | 479,223 | 4,992 | 238,931 | 179,677 | 55,623 |
| 20-50 | 2,450,807 | 66,605 | 1,440,994 | 739,929 | 203,279 |
| More than 50 | 12,568,155 | 427,211 | 7,171,914 | 4,042,850 | 926,180 |
| Wausau | | | | | |
| Less than 20 | 384,067 | 17,374 | 227,804 | 107,767 | 31,122 |
| 20-50 | 2,282,846 | 119,789 | 1,186,525 | 801,536 | 174,996 |
| More than 50 | 12,831,272 | 361,645 | 7,437,510 | 4,053,153 | 978,964 |
| Wisconsin Rapids | | | | | |
| Less than 20 | 230,160 | 4,042 | 99,883 | 92,780 | 33,455 |
| 20-50 | 1,756,757 | 61,687 | 937,941 | 592,031 | 165,098 |
| More than 50 | 13,511,268 | 433,079 | 7,814,015 | 4,277,645 | 986,529 |
| Closest wood-using center | | | | | |
| Less than 20 | 4,719,574 | 138,057 | 2,644,856 | 1,551,433 | 385,228 |
| 20-50 | 9,144,620 | 297,162 | 5,220,578 | 2,939,439 | 687,441 |
| More than 50 | 1,633,991 | 63,589 | 986,405 | 471,584 | 112,413 |



☆ U.S. GOVERNMENT PRINTING OFFICE: 1989—657-720/48

Hahn, Jerold T.; Hansen, Mark H.

1989. **Operability and location of Wisconsin's timber resource**. Gen. Tech. Rep. NC-134. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 42 p.

Data collected during the 1983 Wisconsin Statewide forest inventory were used to examine operability of the timber resource based on seven operability components. Operability is the ease or difficulty of managing or harvesting timber because of physical conditions in the stand or on the site.

**KEY WORDS**: Management opportunities, forest inventory, prime forest land, harvesting, accessibility.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION

United States
Department of
Agriculture

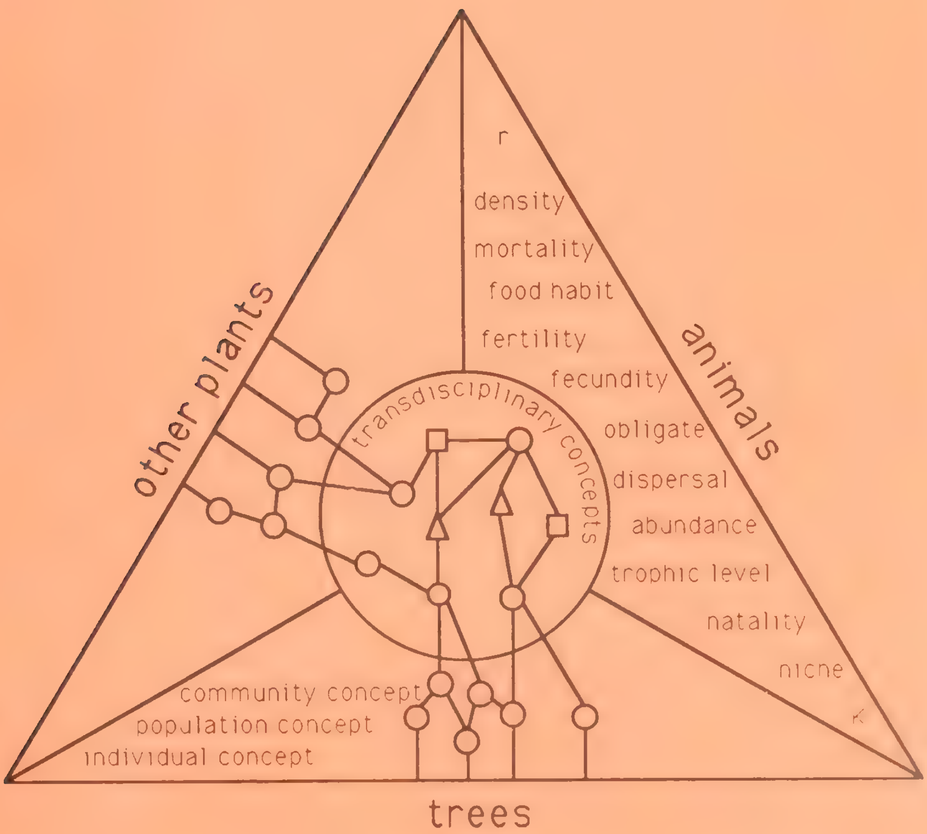
Forest
Service

North Central
Forest Experiment
Station

General Technical
Report NC-135

# Discovering New Knowledge About Trees and Forests






IUFRO

The cover design is adapted from ideas presented in:

Day, John A. 1952. The methodology of physics extended to other fields. Main Currents in Modern Thought 9(3): 67-71 (also note the cover design for the issue of MCMT).

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# DISCOVERING NEW KNOWLEDGE ABOUT TREES AND FORESTS

Selected Papers from
a meeting of IUFRO Subject Group S6.09:
Philosophy and Methods of Forest Research

held at

Michigan Technological University
Houghton, Michigan, USA 49931
August 19-23, 1985

Hosted by: Department of Forestry
Michigan Technological University

Meeting Organized and Papers Compiled by: Rolfe A. Leary
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## PREFACE

Subject Group 6.09 — Philosophy and Methods of Forest Research — was organized at the 1981 IUFRO World Congress in Kyoto, Japan. It is the newest subject group in Division 6 of IUFRO, and one of the youngest of all the Divisions. Two important reasons for organizing such a group were spelled out at the Kyoto meeting: 1) to improve the quality of scientific research done on trees and forests, and 2) to enhance the state of forestry as a science. The primary goal of the group during its early years of existence has been to identify persons with a strong interest in philosophy of science and scientific research methods and to help others to know who shares their interests. One method for accomplishing this is to bring the identified persons into contact, either directly through participation in small meetings such as the one reported on here, or indirectly through the publication of the papers, or abstracts of papers, delivered at the meeting.

The 1985 meeting of 6.09 was not large compared to the meetings of some subject groups, but it was marked by a high level of interest and enthusiam for the subjects being discussed. When the meeting was being planned, I did not anticipate publishing the papers. During the meeting, a number of participants asked that a proceedings be prepared. Some who gave papers did not prepare their comments in written form. I have included the abstracts here that were distributed at the meeting so that others may know of their interests. I omitted abstracts submitted prior to the meeting if a paper was not presented. My apologies to the participants for taking so long to get the papers published.

I thank Dr. Ed Frayer, Dean, School of Forestry, Michigan Technological University, who kindly offered the support of the Department in organizing the meeting.

A special thanks to the Division of Education and Public Service at Michigan Tech, especially to Ms. Sue Bucheger, who did a find job of managing the details of meeting prepartion and made my first experience at such a task a thoroughly enjoyable one. I am especially thankful for the bright sunshine that arrived wednesday afternoon for our picnic on the shores of Lake Superior during an otherwise rainy week.

I also thank Dr. Robert Hann, Director of the North Central Forest Experiment Station at the time the meeting was held, for allowing me to work nearly full time on preparations following my return from Michigan Technological University, and for granting permission for a number of North Central employees to attend the meeting.

Finally, I thank the participants who travelled the long way to Houghton, and who shared their views on a diversity of topics. Those who prepared manuscripts for this document have my special gratitude.

Rolfe A. Leary<br>St. Paul, Minnesota<br>April 1989

# GRADUATE INSTRUCTION IN THE RESEARCH PROCESS

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**Abstract:** Most new graduate students arrive ill-prepared for initiating and carrying out their first research project. The old rules that guided them to success and high grades in undergraduate courses are no longer of paramount importance, but rules for performing the new task —research—are poorly defined. In addition, ideas about research and researchers derived from the published literature may lead to unrealistic expectations, wasted time, conflicts with advisors, and needless discouragement. By formalizing activities related to initiating research, and by giving students a clearer and more realistic view of the research process, a research orientation course or seminar can facilitate the successful transition from undergraduate to graduate school. Fundamental goals for an introductory research course should include making research a less intimidating prospect, providing a sequence of tasks that minimizes procrastination and provides direction, giving encouragement for the students' initial efforts, providing criteria for making informed decisions and judging performance at critical stages in the research, and helping students develop realistic expectations of themselves and their advisors.

## INTRODUCTION

New graduate students, especially new master's degree candidates initiating their first research projects, have unique problems and needs as they strive to meet the challenges presented by graduate school. Serious consideration of these problems and needs is an essential step toward developing improved methods of teaching the research process.

As we are all well aware, the quantity and quality of information about the research process available to graduate students from their departments, colleges, and individual research advisors lacks uniformity. In fact, the research training environment to which graduate students are exposed is so variable that their ability to do independent research would probably differ greatly even if all of them started with equal ability and motivation. Some time ago I discovered that one basic principle explains most events in life. This principle is embodied in Stock's Second Law: All things are random. More than we care to admit, this law applies to graduate education and research, especially the first research project undertaken by a new graduate student. The luck of the draw too often pertains in, for example, choice of graduate schools, advisors, and thesis topics.

In addition, many unwarranted assumptions are made about the advisor/advisee relationship and the research training environment. A few of the more universal and illogical of these assumptions lead to poor quality research training, and hinder development of a truly effective, formalized, systematic approach to research instruction. In spite of these obstacles, however, many departments have research courses or seminars, but their content, format, and emphasis varies widely — more widely than does, for example, the content of a basic silviculture or forest entomology course. Guidelines or even textbooks appropriate for research methods courses are not widely available. While professors might agree on, say, the content of an introductory statistics course, there seems to be little agreement on the content of a course on the even more important and fundamental subject of research. To understand why research training is so variable and especially why some research training is so poor, I'd like to explore some of the fundamental and erroneous assumptions that hinder open communication and exchange of ideas on research methods instruction.

## ASSUMPTIONS

**Assumption (Myth) #1**

Knowing that they have been screened for appropriate undergraduate course-work and a minimum GPA, we assume that *graduate students are well-prepared for graduate school*, including initiating a research project, given a bit of guidance by an advisor.

Most educators are aware that to best teach new behavior, students must be provided with clearcut criteria or standards for judging their performance at the new task at various stages in the learning process, not just at the time of the exam or thesis defense. The best teachers provide these criteria, thus permitting more of their students to do well. Learning becomes a less random, better directed process.

But graduate students arrive at graduate school not knowing what the appropriate performance criteria for research are. The performance criteria that they learned to excel at as undergraduates — studying for grades in a structured setting — no longer pertain in any really important way in graduate school, but the criteria for the new task — research — are ill defined. In research, for example, there is usually no clearly prescribed sequence of tasks, and there is little formal or regular evaluation of progress. These differences between undergraduate courses and research are not minor. New graduate students think that the game simply gets harder when in truth they are playing a whole new game with lots of new rules. All the skills learned to get A's are not particularly useful, *but the students don't know that*. Therefore, early graduate training in the research process should focus, at least in part, on the way the new game is played. Without some orientation in this regard, students can become discouraged, frustrated with their advisors, and waste time. (In some cases they quit, and the university may lose considerable time, money, and other resources invested in those students.) They will not have a realistic perspective of this new adventure and will not be able to efficiently and effectively get at the job of learning to do research.

**Assumption (Myth) #2**

We also tend to believe that *all professors are good* (or at least adequate) *research advisors*. Clearly this is not true, but the way students select advisors, and the way professors select advisees, often seem to be based upon this assumption. The guidance received by the student, based on the one-to-one relationship between advisor and advisee, varies from excellent to abysmal. The relationship between having earned a Ph.D. and being a skilled advisor is as tenuous, perhaps, as the relationship between being able to produce a child and being an effective parent. An additional set of skills must be learned. A minority of individual professors are, through talent or, more often, hard-earned ability, excellent research counselors and instructors. Most of the rest are wise advisors to at least some of their students some of the time. I'd like to briefly itemize a few obstacles that arise at one time or another in the advisor/advisee relationship. These obstacles contribute to the "randomness" of research training and can serve to emphasize the problems inherent in a system that too often relies almost entirely on research instruction by individual advisors.

- **Unrealistic (overly high) expectations for guidance**. Having been guided by their undergraduate teachers, many graduate students expect their advisors to take the lead, not knowing that it is they who must take the lead in the graduate program.
- **Personality differences**. Researchers range from creative and impulsive to systematic, from authoritarian to democratic. Conflicts can arise between an advisor and student with basic differences in research or leadership style.
- **Excessive faith in trial-and-error learning**. Most researchers learned a great deal of their craft through trial and error. As graduate students, they were thrown in the water and learned to swim, so they believe (to some extent perhaps correctly) that this is a good way to sort out the qualified from the unqualified researchers of the the future.
- **Heavy work load/not enough time**. Unfortunately, many faculty members (perhaps especially the most competent

and professionally involved ones) are genuinely too busy to take the time they would like to take to work with each of their students.

•**Increasing dependence on learning by osmosis**. New assistant professors usually spend a great deal of time working out the nuances of research with their first graduate students. However, after doing this a few times, less and less effort may be put into it. Advisors begin to assume that subsequent generations of graduate students will absorb the appropriate "street smarts" from their predecessors once they've gotten the ball rolling.

•**Fading memories**. In most researchers, memories of the anxieties, questions, and self-doubts that they felt about their own early research efforts tend to fade as they gain self-confidence. It's harder to recall the initial fears and problems once you've mastered the game.

•**Overemphasis on methods**. Finally, even when advisors make a real attempt to communicate with their advisees, it is much too easy to focus on the methods. Often a student will come to an advisor with a difficult and usually ill-defined intellectual problem and the two will end up rummaging in a drawer looking for a different kind of lens or making phone calls about some piece of equipment, the real intellectual issue set aside because neither the student or the advisor could easily deal with it. Fortunately, some activities routinely required in graduate programs, such as oral exams and seminars, provide a degree of formalized group discussion of the intellectual aspects of the research process.

**Assumption (Myth) #3**

*The research process is logical and straightforward, and thus easy to teach.* The fact of the matter is that research only appears logical and straightforward after it is tidied up for publication. The more coherently a scientist writes, the more an illusion of order can be created from disorder. Although this practice has many important benefits for the dissemination of knowledge to the scientific community as a whole, students having read about research in textbooks or journal articles enter graduate school with a stereotyped and unrealistic notion of what research is all about. Students doing research are regularly faced with discrepancies between the model of research provided by texts and teachers and the realities of how research is actually conducted. This tends to make the students feel that much of what they are doing is wrong because it does not match the published research accounts that they accept as performance standards. The discrepancies between what they think they should be doing and what researchers actually do can be disorienting and discouraging.

The idealized concept of research and the writing style required by journals suggests that research moves in an orderly, step-by-step manner from background theory and observation to problem definition. A hypothesis is formulated and tested, then accepted, rejected, or modified. Finally, the new information is added to the body of background theory used to do further research.

Actual day-to-day research differs a great deal from this simplified model. Actual research consists of a number of closely related activities that overlap continuously, rather than follow a prescribed sequence. In most research there is no clear end point. Because of time and reporting constraints, an end point must be imposed upon an essentially endless process. (According to Lanier's Axiom, a research project is never completed: it is merely abandoned when the ratio of cost — in dollars or effort — to results becomes less favorable than that of another project or enterprise.) Beginning researchers are also unaware of the amount of change and revision involved in research, since they see only the final product in the literature. They also often do not know that a research subject is often chosen for nontheoretical reasons, such as the availability of support funding, and only afterwards is it given a theory-based justification.

Finally, one of the largest differences between research as it is described in the literature and actual research is that actual research involves many additional activities that are rarely, if ever, mentioned in publications. These activities include logistics (the management of money, people, facilities, and

time), intellectual activities (such as those involved in the generation of ideas or hypotheses), and communication. Writing and speaking coherently and eloquently about research are not automatically derived from doing research (not even from doing very good research), but they are an extremely important part of the process.

## DISCUSSION

By formalizing activities related to initiating research, a research orientation course or seminar can give students a clearer and more realistic view of the research process and facilitate their successful transition from undergraduate to graduate school. Fundamental goals for graduate research instruction should include: making the prospect of research less intimidating; providing students with a sequence of tasks that minimizes procrastination and provides direction; giving encouragement for the students' initial efforts; providing students with criteria for making informed decisions and judging their performance at critical stages in the research; and helping students develop realistic expectations of themselves and their advisors.

Practical aspects of research are particularly important in such instruction. In addition to the standard information on research history, philosophy, and methods, an introductory course can also include information on research management (e.g., planning, time management, budgets), the creative process (e.g., idea generation, the role of chance in discovery), and communication (both writing and talking). Development of individual research proposals during the course increases interest in the subject matter, adds motivation, and provides continuity and integration of all course elements.

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# TEACHING SCIENTIFIC REASONING

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**Abstract**. Scientific research is a problem solving activity. Fortunately, ability in problem solving is a skill, like swimming and piano playing, that can be developed by practice and imitation. The development of problem solving ability ought to be a major educational objective of postgraduate instruction in research methods. To achieve this objective, students must be challenged with problems that provide an opportunity to practice inductive reasoning, the formulation of conjectures, and the critical evaluation of empirical evidence. The books of George Polya contain many such problems, and much more. I will discuss a selection of his problems, and my experience with using them to teach problem solving to graduate students in a Canadian university.

I teach research methods to beginning graduate students in the School of Forestry at Lakehead University. My objective in presenting this paper is to discuss one facet of that course: teaching scientific reasoning. I emphasize this topic for two reasons. First, as a prerequisite to a successful scientific career, students must understand, as thoroughly as possible, the scientific method and the nature, origin and limits of scientific knowledge. Understanding scientific reasoning is, in my opinion, the key to these insights. Second, teaching thinking skills, of which scientific reasoning is an example, is more difficult than teaching either declarative knowledge or technical skills. Hence, there is a greater need, I think, for teachers to share their ideas in this area than in any other.

In spite of the narrow emphasis of this paper, my course covers a balanced blend of information about research. In the hope that this balance will show through, I will begin with an overview of the course's content and my philosophy of teaching research methods.

## THE QUESTION OF WHAT TO TEACH

In deciding what to teach, I have asked myself "What does a scientist have to know?" Of course, s/he has to know a lot, but most of the material can be classified into two broad categories. One category covers heuristic knowledge. The heuristic knowledge of a scientist includes problems solving and reasoning skills. But, it covers a host of other, less tangible, and perhaps intuitive elements as well. For example, I think that many scientists eventually develop a hierarchy of aesthetic values about research that influences their own work, for better or worse, in a variety of subtle ways. Scientists rely on heuristic knowledge when they decide what to do and how to do it, and when they decide what their results mean.

The other subject matter category covers a diverse body of technical skills and knowledge. Some of these are general purpose items, e.g. the skills and knowledge associated with the design of experiments; others are specialized items, e.g. the skills and knowledge associated with tissue culture or electron microscopy. Scientists use these tools whenever they actually do some research (as opposed to just thinking about it).

In my research methods course, I cover both the heuristic and general technical aspects of the subject. The technical topics covered include the basic principles of research problem analysis, library research, project planning, experimental design, proposal writing, the execution of experiments, data analysis, and the communication of research results. The heuristic topics covered include problem solving and reasoning skills. I do not, however, teach the less tangible elements of a scientist's heuristic knowledge, at least not explicitly. Probably this knowledge cannot be taught in any large

measure in a formal course, but instead grows out of one's personal, lifelong experience with science.

## THE QUESTION OF HOW TO TEACH

### Teaching Technical Skills and Knowledge

The set of rules for deriving the expected mean square terms in an ANOVA table is an example of a technical information topic. Information topics are relatively easy to communicate. Conventional methods include lectures, assigned readings, and if the material lends itself, hands-on practice. Practice is especially necessary when the educational goal is to develop a skill as opposed to the communication of declarative knowledge.

To provide practice with some important research related skills, I ask my students to undertake a research problem analysis, to write a research grant proposal, and to deliver a seminar on a technical subject. I also assign a series of homework problems that exercise experimental design skills.

### Teaching Problem Solving and Reasoning

My personal experience, and I believe that of others, has been that it is more difficult to teach thinking skills (e.g. problem solving and reasoning) than it is to teach either technical skills or declarative knowledge. In the remainder of this paper, I discuss why this is so, and I outline a few ideas for overcoming these difficulties.

#### What are problem solving skills?

The inputs to the research process are problems. It is not surprising, therefore, that successful scientists are good problem solvers, at least within the domain of their own research. Expert problem solvers have many characteristics in common regardless of the nature or context of the problems themselves. For example, expert problem solvers are aware of, and use a problem solving (PS) strategy. Experts also understand the need to alternate between direct PS activities (e.g. gathering information or perfoming calculations) and PS management activities. Occasions when experts jump in and out of their role as PS manager include: 1) when they want to assess where they are, and where they are going, in the PS process, and 2) when they are stuck. In the latter case, experts know a variety of ways to get unstuck. For example, they may "work backwards", consider simplified cases, or seek and use analogies.

#### What are reasoning skills?

In my experience, many students begin graduate study with several misconceptions about the process by which new scientific knowledge is acquired. Of course, there is much variation between students. I suspect at least two reasons for this situation. First, the (North American?) educational system, up to and including much of the undergraduate university level, is concerned with the communication of what is "known". Often little is said, however, about how the current state of knowledge came to be. Second, science and mathematics textbooks, especially at the introductory level, often give the impression that science proceeds largely through the use of deductive reasoning. Perhaps this orientation is a natural consequence of the desire to compactly and systematically communicate "the facts".

Experienced scientists, on the other hand, have quite a different view of how new knowledge is acquired. They know that in the course of a single research effort they will use a whole spectrum of reasoning skills. These range from strictly formal deductive reasoning to more or less informal inductive reasoning. Experienced scientists understand further that the conclusions drawn from empirical evidence always must be based on inductive reasoning. They appreciate the limitations of such conclusions, and all that this implies about the nature and limits of scientific knowledge itself.

Clearly, the transition from beginning graduate student to mature scientist involves, among other things, the acquistion of a collection of reasoning skills and attitudes about evidence, truth and knowledge that is both broad and deep. Polya (1954, 1968) refers collectively to these skills and attitudes as "the art of

plausible reasoning". It would be good if these things could be taught.

**The trouble with teaching thinking**

There are two sources of problems that must be overcome in order to effectively teach thinking skills such as those outline above. First, both student and teacher must understand that thinking is a skill. The fact that it is is good news because it means that accurate, efficient thinking can be learned as other skills are learned through practice and imitation.

The second problem stems from the fact that thinking is an invisible skill. Thus, while a student of, say, swimming can observe and analyze the techniques of an expert, a student of thinking cannot — at least not without some extraordinary cooperation on the part of the expert.

The rest of this paper is about solving these two problems.

**Sources of ideas about teaching thinking**

There is a rapidly growing body of literature on problem solving. This literature deals both with general problem solving methods and with methods of teaching problem solving. One valuable source of this information is PS news, a newsletter by Dr. Don Woods (see literature Cited). PS news is also a helpful guide to the wider body of PS literature.

Through PS news, I discovered the books of George Polya. "How to solve it" (1957) is well known and worthwhile. However, Polya's other books on problem solving (1962, 1965) and the art of plausible reasoning (1954, 1968) are even better sources of general PS methods and teaching ideas. Also through PS News, I learned of the work of Drs. Arthur Whimbey and Jack Lochhead. Their book (1982) and an earler article (Whimbey 1977) discuss the problem of how to make thinking a visible skill.

**Teaching problem solving and reasoning as skills**

Until recently, I tried to teach "the logic of scientific discovery" as factual information. I assigned readings (e.g. Russell 1931, Popper 1962, 1968, Bunge 1967a,b) and gave lectures on the philosophy and methods of science. While these efforts were not completely wasted, I now believe that a more effective teaching technique is one that allows students to actually practice the problem solving and reasoning skills associated with doing research. The question is where to find a suitable setting in which practice research can take place.

Analogy is a powerful aid to understanding complex ideas. Therefore, I believe that the object of study of practice research ought to be a system, since a system is the object of study of much real research. Furthermore, the goal of practice research ought to be to discover the rules that govern the system's behaviour, since the discovery of governing rules is the goal of much real research. In short, it seems reasonable to make the analogy between real and practice research as strong as possible. I am about to suggest, however, that there is a limit.

At this point, the search for the ideal practice system becomes complicated by two factors. First, the ideal practice system must be at the right level of difficulty. It should be possible, for example, for graduate students of average ability to make significant progress towards understanding the behaviour of the practice system in, say, a few days. Second, I feel that the ideal practice system ought to be noise-free. I will explain this last statement since it may seem contradictory. After all, the educational goal is presumably to train natural scientists, and natural systems are anything but noise-free.

**The case for noise-free practice research systems**

Natural scientists face two problems in the course of their research. First, they must extract meaningful information about system behaviour from a set of noisy observations on the systems. Second, they have to use this information as a ground for discovering the rules that govern the system's behaviour. The body of knowledge that treats the first of these problems is statistics. The body of knowledge that treats the second might be called "scientific reasoning".

Of course, statistics and scientific reasoning are separate topics, and in my opinion, the best policy is to teach these two topics separately. That way the fundamentals of scientific reasoning can be seen clearly. This separation can be accomplished if the principles of scientific reasoning are taught by means of practice research in a noise-free setting. Once students understand these principles, statistics can be presented as a tool for coping with the special problems of noisy systems.

**Two noise-free practice research systems**

Mathematics is a rich source of noise-free systems that span a wide range of complexity. The two problems that follow are from Polya (1954).

THE TRIANGLES PROBLEM: The 3 sides of a triangle are of lengths l, m, and n respectively. The numbers l, m, and n are positive integers such that l is less than or equal to m, and m is less than or equal to n. Find the number of different triangles of the described kind for n = 1, 2, 3, 4, 5,.... Find a general law governing the dependence of the number of triangles on n.

THE LAST INTEGER PROBLEM: Try to discover the rule that governs the following table.

| a | b | Last integer that **cannot** be expressed in the form aX + bY |
|---|---|---|
| 2 | 3 | 1 |
| 2 | 5 | 3 |
| 2 | 7 | 5 |
| 2 | 9 | 7 |
| 3 | 4 | 5 |
| 3 | 5 | 7 |
| 3 | 7 | 11 |
| 3 | 8 | 13 |
| 4 | 5 | 11 |
| 4 | 6 | 19 |

The numbers X and Y must be non-negative integers.

On the first reading, it may not be apparent that these two problems exercise the patterns of reasoning used by natural scientists. To partially appreciate this fact that they do, notice that both problems preserve three important elements of real research in the natural sciences. First, in both problems the object of study is a system. Second, both systems transform (map) input values onto output values in a way that is at first puzzling (so there is a phenomenon to be investigated). And, third, the research problem in both cases is to discover the rules that govern the system's mysterious behaviour.

To fully experience that these problems exercise scientific reasoning skills, you should solve them yourself. Of course, in doing so you must limit yourself to the experimental methods of a natural scientist, and avoid the special methods, e.g. mathematical induction, of the mathematician. As an alternative to solving both problems yourself, I have outlined in the Appendix the steps taken by several graduate students in the course of solving the Triangles Problem. If you wish, read the Appendix before continuing.

**Making thinking a visible skill**

I mentioned earlier that thinking is an invisible skill, and, therefore, inherently more difficult to teach than a visible skill like swimming. In the case of teaching scientific reasoning, the problem for both the teacher and the student is to discover how the student thinks while s/he is attempting to solve a research-type problem. Only then can errors in reasoning be discovered and corrected and good habits reinforced. Three educational methods for making thinking visible are: group discussion, Whimbey-pairs, and student PS chronicles. Let's consider each of these in turn.

**Group discussion**

One of several educational applications of discussion groups is to teach analytical thinking and reasoning (McKeachie 1978). Therefore, one might be lead to believe that this method would be ideal for teaching scientific reasoning. My own efforts in this direction, however,

have often been disappointing. Hence, while the method is of value, and ought to be used, it is not foolproof.

Some of the things that get in the way of productive class discussions are these:

1. Students do not know how to participate in a discussion group.

Beginning graduate students are not necessarily skilled at participating in group discussions. When this seems to be the case, it may be wise to invest a little class time teaching the fundamentals.

2. Students lack sufficient knowledge about the topic under discussion.

Individual students may feel that they have not progressed far enough in their thinking about science to enter a discussion. Often, beginning graduate students have only limited personal experience with independent research. Practice research problems provide one source of common experience upon which class discussions can build.

3. Students are reluctant to reveal their thoughts in public.

This may be the biggest obstacle to fruitful class discussion. When it is a problem, it may be due to the next item.

4. The teacher is unskilled as a discussion leader.

Students know that my motive for group discussions is to get their thinking out in the open. This strains our relationship, especially when they believe that their thoughts are contrary to my own on the issue under discussion. Fortunately, there are several helpful source books with advice on how to resolve such problems. Two good ones are Auer and Ewbank (1954) and Maier (1963).

**Whimbey-pairs**

Whimbey (1977) discussed the use of a method for teaching cognitive skills in which students work in pairs or small groups. Briefly, Whimbey asks one student in each pair to solve a problem aloud while the second student listens. Whimbey choses problems that exercise problem solving and reasoning skills. The problem solver is instructed to vocalize everything that s/he thinks about in the course of attempting to solve the problem. The listener is instructed to check for errors in the problem solvers reasoning, monitor his/her PS strategies, encourage the problem solver to vocalize thoughts when s/he is silent, and so on. The members of the pair switch roles with each new problem.

The Whimbey-pair method focuses attention on the fact that problem solving is a learnable skill, and that there are general methods that work on a wide variety of problem situations. Because problem solvers work with their thinking revealed, it is possible for others to see (hear) how different individuals think when they are in a problem solving situation. Thus, students can learn good habits from each other.

Fortunately, most beginning graduate students are good at solving the short, reasoning-type problems that Whimbey uses. Unfortunately, the Whimbey-pair method does not lend itself directly to practice research problems like the two given above because these problems take too long to solve.

**Student PS chronicles**

My solution to the problem of making thinking visible in a practice research setting is to ask students to keep a chronicle of their problem solving efforts. I assign a problem like either of the two given above, and give the class several days to work on it. Periodically, we discuss their progress to date, but without giving too much away to those still working. Throughout, I emphasize that it is the reasoning process, and not the "right answer", that should be the focus of their attention.

When all of the students have experienced at least some measure of success, we spend a class period reviewing the research methods that various members of the class used in the course of their work. In these "debriefing sessions", I point out general types of problem solving activities and reasoning patterns that occur in their chronicles. These include: the collection of initial

observations, searching for patterns, guessing what might be true, figuring out critical tests, performing these tests, weighing evidence, and various examples of plausible reasoning that were involved in drawing conclusions.

## CONCLUSIONS

Scientific reasoning is one of several topics covered in a graduate level course on research methods. The educational objective of this segment is to teach students how to think like scientists. Since scientific reasoning is a skill, it is taught by having students undertake practice research. The practice research preserves two attributes of real research in the natural sciences. First, the object of study is a system, and, second, the goal of the research is to discover the rules that govern the system's behaviour.

Two problems must be overcome before these ideas can be fully implemented. First, when novices consider real research, the thread of scientific reasoning may be lost in a maze of statistical procedures. It is desirable, therefore, to teach scientific reasoning and statisitics as separate topics, at least initially. The principles of scientific reasoning can be isolated by basing practice research on noise-free systems. Second, thinking skills, like those involved in scientific reasoning, are invisible. Therefore, special teaching methods are needed to focus attention on the process of correct reasoning, and on the good and bad reasoning habits of individual students. Some of these special methods were discussed.

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## APPENDIX: A CLOSER LOOK AT THE TRIANGLES PROBLEM

Many students begin by trying to clarify the problem. They do this by rereading the problem statement, and by examining some particular cases of n to see how n affects the size of the family of triangles associated with n. Everyone begins by looking at the simplest cases, n = 1, 2, 3, .... (Notice that this is an experimental approach, even though the experimental results ar noise-free, and the conclusions drawn are necessarily inductive.)

Eventually, the student researcher discovers two things:

a) there is a systematic way to write down the triangles that belong to any particular family, and

b) some of the allowed combinations of l, m, and n are not triangles.

The allowed combinations of l and m for n equal 4 are presented in Table 1.

By this point the PS'er , if s/he is so inclined, can see that the problem situation in terms of an input-output system. The sytem accepts whole number, n = 1, 2, 3, ....., as input and transforms these into another set of whole numbers that represent "the number of different triangles of the described kind". Let's call these second values S(n).

Table 1. The allowed values of l and m for n equal 4 presented systematically and without regard to whether the result is a triangle.

| n | m | l | Is it a triangle? |
|---|---|---|---|
| 4 | 4 | 4 | Yes |
| 4 | 4 | 3 | Yes |
| 4 | 4 | 2 | Yes |
| 4 | 4 | 1 | Yes |
| 4 | 3 | 3 | Yes |
| 4 | 3 | 2 | Yes |
| 4 | 3 | 1 | No |
| 4 | 2 | 2 | No |
| 4 | 2 | 1 | No |
| 4 | 1 | 1 | No |

A natural scientist at this stage of understanding might develop a table showing the relationship between n and S(n) in particular cases. Student researchers do this as well (Table 2).

By now the PS'ers has some experience with how the system works. It remains, however, to discover the rule that governs the relationship between n and S(n). As experience accumulates, most PS'ers discover that, somehow, it makes a difference whether n is odd or even, and they sort their results accordingly (Table 3).

Table 2. The first 10 values of n and S(n)

| n | S(n) |
|---|---|
| 1 | 1 |
| 2 | 2 |
| 3 | 4 |
| 4 | 6 |
| 5 | 9 |
| 6 | 12 |
| 7 | 16 |
| 8 | 20 |
| 9 | 25 |
| 10 | 20 |

Table 3. Values of n and S(n) sorted according to whether n is odd or even

| n | Odd values of n S(n) |
|---|---|
| 1 | 1 |
| 3 | 1 + 3 = 4 |
| 5 | 1 + 3 + 5 = 9 |
| 7 | 1 + 3 + 5 + 7 = 16 |
| 9 | 1 + 3 + 5 + 7 + 9 = 25 |

| n | Even values of n S(n) |
|---|---|
| 2 | 2 |
| 4 | 2 + 4 = 6 |
| 6 | 2 + 4 + 6 = 12 |
| 8 | 2 + 4 + 6 + 8 = 20 |
| 10 | 2 + 4 + 6 + 8 + 10 = 30 |

The pattern in Table 3, once it has been discovered, leads to the following hypothesis.

Hypothesis 1: The number of triangles depends upon whether n is odd or even according to the following rule

$$s(n) = \begin{pmatrix} 1+3+\ldots\ldots\ldots\ldots+n & \text{if } n \text{ is odd} \\ 2+4+\ldots\ldots\ldots\ldots+n & \text{if } n \text{ is even} \end{pmatrix}$$

Some students believe that Hypothesis 1 is the "general law governing the dependence of the number of triangles on n". Others, however, guess that the rule can be expressed more concisely. Following this intuition, for odd values of n, leads to another tabulation of the observations as shown in Table 4.

Table 4. The relationship between n, the rank of n as an odd integer, and S(n)

| n | Rank of n in the odd integers | S(n) |
|---|---|---|
| 1 | 1 | 1 |
| 3 | 2 | 4 |
| 5 | 3 | 9 |
| 7 | 4 | 16 |
| 9 | 5 | 25 |

Recognition of the pattern in Table 4 leads to the following hypothesis.

Hypothesis 2. When n is odd, S(n) is the sum of the first (n + 1)/2 odd integers which is given by

$$s(n) = \left(\frac{n+1}{2}\right)^2$$

Flushed with this success, it is easy to discover the general law for the case of even n.

# THE CASE METHOD IN TEACHING RESEARCH METHODS

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**Abstract**. I teach a research methods course in the USU College of Natural Resources, mainly to graduate students in forestry, recreation, wildlife, range, and hydrology. It also attracts students from biology and ecology. The course covers the scientific methods of induction, retroduction, hypothetico-deduction, and analogy. It also covers several methods used in planning research.

I use the case method to simulate the research process. I have patterned it after the way it is done in business schools. I take a piece of published research from some source like Science magazine, and write the case up by presenting the student with the objective of the research and all the "givens." Then I ask them to complete the research design and present and defend it in class. The students do not know where the problem comes from. For example, a case typically posses a hypothesis and presents all the kinds of facts that can be experimentally obtained. The student has to deduce test predictions from the hypothesis and design the experiment.

I will pass out copies of several cases for you to take home, think about, and judge their effectiveness as a teaching tool.

This paper explains the case method of teaching, describes its use in a research methods course given to graduate students in forestry, recreation, wildlife, range, hydrology, ecology, and biology at Utah State University, and illustrates a case that is used in the class.

## CASE METHOD OF LEARNING

Most learning in college is passive: through lectures the instructor loads the minds of students with facts, laws, and theories. The case method of learning is designed to allow students to derive principles rather than have principles announced to them. The first credited use of the case method was in 1871 at Harvard Law School. Around 1910 it was subsequently adopted at Harvard Business School.

There are two kinds of cases. In the **issue** case, the students are given a real unstructured problem, complete with background and context, and they must synthesize a solution. In the **descriptive** case, the students read someone else's solution of an unstructured problem and they criticize it. Unlike mathematical problems, real problems seldom have proposed solutions that others cannot mount challenges against. For this reason, the case method leads to argument and debate, and it promotes creative thinking.

Some of the features of the case method are (paraphrased from The Case Method in Library Education by Thomas J. Galvin):

--Aims primarily to develop an attitude and a way of thinking rather than a technical vocabulary and a long list of established facts.
--By presenting a case to the class and leading a class discussion in which all participate, the student presenting the case and the class share their perceptions with each other; and by trying to find order in the cases, the class can see more and understand better.
--Allows the simulation of real-life conditions — i.e., partially unordered, reasonable unstructured problems in which students discover their modes of response.
--Places the burden of thinking on each class member, forcing the student to formulate, present, and defend sound solutions to a body of problems.
--Helps provide judgment that is often missed when learning is restricted to

memorization of facts and views which others have codified.

--The goal is not the production of "right" answers, but the development of modes of thought and methods of analysis that will result in sound judgment in action.

--Aims to produce "a professional personality." By forcing the student to explore for the very heart of a problem and to come up with a practical decision, the student derives a maturity and independence of mind that is not readily available in a typical lecture course.

--The instructor must give just enough guidance so that the student is forced to think, but if too little is given the average student comes away with a fuzzy sense of no accomplishment and a feeling of frustration. In the absence of objectives that are clear to the student, little or no growth takes place.

--One major aim is to develop the qualities of self-reliance and self-confidence in the student.

## CASE METHOD USED TO TEACH RESEARCH METHODS

Both issues cases and descriptive cases can be used to teach the following:

**1) Posing good questions.** For an issue case, the students are given the bounds of a body of knowledge. They search out what is known within the bounds, thereby identifying the gaps. The goal is to pose good questions, i.e., good problems for research. This forces them to choose criteria which define the goodness of a problem in science. For a descriptive case, the students read a published article in which problems were identified, and they critique the scientists' conclusions.

As a device for learning, the issues case is much more effective on this task than is the descriptive case. In general, the main advantage of the descriptive case is in making scientists who have published seem less "godlike": when a student can see how he could have done something better than a mature scientist did, this raises his confidence.

The main difficulty in using the case method to pose questions is that it takes three to four weeks to research what has been done in the area. At most, one or two exercises of this type can be carried out in a term.

**2) Posing good hypotheses.** For an issue case, the students are given background knowledge and the question is stated. For example, the question could be, "How do salmon navigate across an ocean or lake to find the mouth of their home stream?" The students are expected to pose good alternative hypotheses. This forces them to set down criteria for the goodness of a scientific hypothesis.

For a descriptive case, the students are given scientific articles in which the investigator tested a hypothesis and found it to be false. The students are to propose alternative hypotheses to test.

**3) Testing hypotheses.** For an issue case, the students are given background knowledge, one or more hypotheses to test, and background about the kinds of experimental manipulations that are possible. They are to predict consequences of the hypothesis and design an experiment which will give facts to compare with the predicted consequences.

For a descriptive case, the students read an article in which the scientist used the hypothetico-deductive method to test a hypothesis, and they are asked to devise a more efficient test, i.e., one that (1) requires a cheaper experiment, (2) will be subject to less experimental error, or (3) will be otherwise more conclusive.

### An Example of an Issue Case Used to Test a Hypothesis

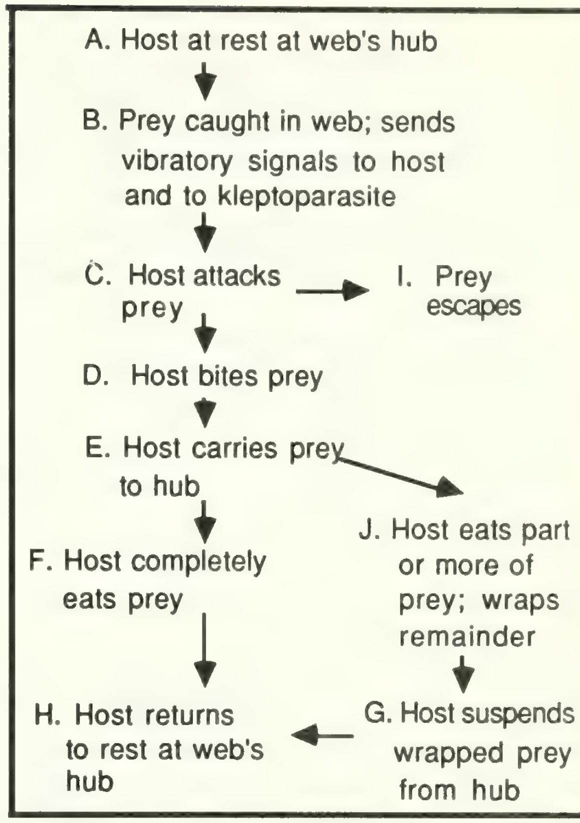
The following case is based on actual research: "Vibrations: Their signal function for a spider kleptoparasite"[1]. Students are unaware of this until after they analyze the case and discuss it in class. Then they are given the article to read and it is discussed and compared to their analyses in the next class.

This is the statement for the issue case:

[1]Vollrath, F. 1979. Science 205(1149-1151).

Tropical spiders of the theridiid genus *Argyrodes* Simon inhabit the webs of other spiders. The kleptoparasitic *Argyrodes elevatus* Taczanowski constructs no web of its own but primarily uses the snares of the orb-weaving spiders *Nephila clavipes* and *Argiope argentata* to secure its food. Fine threads connect its resting place, 20 to 30 cm. outside the host's capture area, with the hub and several radii of the host's web. The kleptoparasites move along these lines either in search of small insects entangled in the sticky spiral, but neglected by the host, or to steal large prey items caught and stored by the host. Raids for stored prey packets are triggered by the host's prey-catching habits, and a distinct stealing behavior is displayed by the kleptoparasites, indicating a high degree of specialization toward either host species.

Since the vision of most web-building spiders is poor and the use of acute olfaction has not been demonstrated, it is generally assumed that vibrations are of major importance to the kleptoparasites, i.e., the vibratory pattern of the host's prey-catching sequences is read and this information is processed and the kleptoparasites adjust their stealing behavior accordingly. The host's prey-catching sequence follows this script:




Each activity in this sequence generates a distinctive vibratory pattern which can be recorded.

When the sequence is filmed, it is usually the case that after step H is completed and the host becomes active again, i.e., moves off the hub, that the kleptoparasite is lured to the hub in search of prey. The host has certain "antiparasitic" behaviors—such as searching for stolen prey or abandoning its present web site for another—which are detrimental to the kleptoparasites. By monitoring the host's movements, a kleptoparasite can reduce the likelihood of being perceived; for example, it avoids moving on the orb when the host is inactive at the hub and most sensitive to vibrations in its web. In addition, an ability to evaluate the vibratory pattern enables the kleptoparasite to adjust its pillaging to the availability of wrapped prey packets and consequently allows it to conserve energy.

We would like to know which event(s) in the prey-catching sequence (below)

A → B → C → D → E → F → H or

A → B → C → D → E → J → G → H

are crucial for informing a kleptoparasite that a trip to the web's hub will probably be profitable. That is, the question is: which vibratory signal(s) constitute information for the kleptoparasite's decision-making model of whether or not food is available?

Remember, each event gives its own characteristic vibratory pattern which is transmitted by the structure of the web to the kleptoparasite. However, it is not clear whether the kleptoparasite can perceive all of these patterns. That is, not all signals are transmitted with equal "strength" and the kleptoparasite's vibratory receptor may not be tuned to all frequencies.

Design one (or more) tests of hypotheses which will isolate which event(s), A through H , is necessary for informing the kleptoparasite that food is available. Write out the hypothesis(es), the test conclusion(s), and the background conditions.

Finally, a note on what is possible in terms of spider experiments. It is **not** possible to artificially induce the web to vibrate in the manner each of the real events A through H would make it vibrate. While it is possible to record the vibratory patterns, attempts at playing them back to the web fail because the inertia of the vibrating mechanism of the playback device distorts the real pattern. It is, however, possible to simulate the signals of a trapped prey, thus inducing the host into attacking the source of the simulated vibrations, even though the prey may or may not be at the source point. It is also possible to feed a prey, or parts of a prey, directly to the mouthparts of the host spider at rest on the hub, in which case the host will either consume all of the food which is proffered, or it will wrap and hang the food. It is also possible to hang wrapped prey collected from other webs without disturbing the host. After the host has carried the prey to the hub (event E) it is **not** practical to remove the prey from the host. It is also possible to remove the host spider from the web at any point in the sequence A through H without the kleptoparasite, it is assumed, being aware. (END OF CASE)

Student's solutions differ in the costs of the proposed experiments, the amount of experimental noise, and in the amount of experimental control that can be exercised. Students also generally feel that the case is a puzzle that is fun to solve. On some cases I allow them to work in teams of two or three people because they seem to profit from sharing each other's ideas.

While this is a classroom exercise and the students can never be as motivated to solve it as the original researcher was, I believe the approach is more effective than having them read the article, observe how someone else was creative, and see how much rubs off on them. If students actively participate and create their own solutions to a variety of problems using the case method, then the premise is reasonable that this prepares them as well as any classroom method can.

The case method of teaching is demanding of the teacher. Good cases are hard to construct. The instructor cannot use a key to grade cases and presentations. Finally, the effectiveness depends on the "chemistry" that develops among members of the class.

# USING SIMULATIONS TO EXPLORE SCIENTIFIC REASONING [1]

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**Abstract**. An important part of preparing science students is to make sure that they understand, in a practical way, the implications of developments in philosophy of science. This paper focuses on Popper's idea that science advances not by proving theories right, but by proving them wrong. Psychologists have developed a number of tasks that simulate this aspect of scientific reasoning. This paper describes three experiments using two of these tasks. The first two experiments demonstrate the value of giving students instruction to falsify, or disconfirm, their hypotheses. The third experiment shows that falsification must be accompanied by replication in situations where there may be error in the data. Classroom simulations that illustrate the value of falsification are derived from each experiment and their actual use in forestry and other science classes is discussed, including suggestions for improved use in the future.

Abimbola (1983) argues that philosophy of science could be used to improve science education. Abimbola particularly emphasizes Popper's (1962) idea of falsification (see Chalmers, 1979, for an introduction to Popper). This article will show how psychologists have designed tasks that simulate falsification, what experimental results they've obtained with these tasks and how these tasks can be adapted for classroom use in forestry and other scientific disciplines.

According to Popper, to be scientific, a theory must make specific predictions which can be falsified, or proven wrong. An example is Einstein's theory of General Relativity, which predicted precisely how much rays of light should be bent in a gravitational field. If results had not accorded with predictions, Einstein's theory would have been falsified.

One implication of Popper's views is that science advances not by proving theories right, but by proving them wrong. Therefore, scientists—and by extension, science students—should search for evidence that has the potential to falsify hypotheses. But as we shall see, psychological experiments suggest that most of us seek confirmatory evidence.

## EXPERIMENTAL STUDIES OF FALSIFICATION

Wason (1960) developed a task designed to model falsification. He told college students that the number triple '2,4,6' was an example of a rule. He asked them to guess the rule by proposing as many additional number triples as they liked; every time a student proposed a number triple, Wason indicated whether it corresponded to the rule or not. When students thought they had discovered the rule, they announced their guesses and Wason told them whether they were right or wrong. Note some of the ways in which reasoning on this task is analogous to science. Each triple can be regarded as an experiment and the rule the students are trying to discover is like a scientific law. Faust (1984) discusses why research using simulations like the 2-4-6 tasks is relevant to science.

Wason noticed that most of the students would propose strings that were positive instances of their hypotheses, e.g., if a student thought the rule was 'numbers must go up by twos' he or she might propose '8,10,12' '14,16,18' and '21,23,25'. All these triples are instances of the rule and so the student would confidently announce that his or her hypothesis was the rule. Wason took this as evidence of a 'confirmation bias' on the part of the students: very few of them played triples like '1,2,3' that should be **wrong** if the rule were 'number ascending by twos.' In other words, students failed to seek evi-

[1] An earlier, longer version of this paper appeared in School Science and Mathematics, 1986, 86(4):306-321 under the title, "Falsification in Experimental and Classroom Simulations".

dence that had the potential to falsify their hypotheses. In fact, the triple '1,2,3' is a correct instance of the rule; this information decisively disconfirms the 'numbers ascend by two's' hypothesis. Because of their confirmation bias, many students had trouble guessing the correct rule, which was simply that the three numbers must ascend in order of magnitude. Mahoney (1976) found that scientist's displayed a similar confirmation bias on this task. (For an alternative interpretation that replaces the term 'confirmation bias' with 'positive test heuristic', see Klayman and Ha 1987).

Tweney et al. (1980) wanted to see if they could combat this confirmation bias by giving students additional training. So they instructed students to employ either a confirmatory or a disconfirmatory strategy on this task. Students given the disconfirmatory instructions did try to falsify their hypotheses more often than students instructed to confirm, but the former did not solve the rule significantly more often than the latter.

One of the problems with Tweney et al.'s study is that, like Wason, these researchers told students not only whether each of their triples was right or wrong, in terms of the rule, but also whether each of their announced hypotheses was right or wrong. For example, a subject who announced that the rule was 'numbers ascending by twos' was told that his/her hypothesis was wrong and was allowed to continue the task. Note that the experimenter has, in effect, falsified this subject's hypothesis.

It occurred to me that the true value of instructing students to falsify would only become apparent if the student's had to decide whether their hypotheses were right or wrong without being able to ask the experimenter. As Tweney, Doherty and Mynatt (1981) point out, falsification is most useful late in the inference process, when the scientist already has a clearly-formulated hypothesis. Similarly, falsification would be most effective on Wason's task after students had formulated a hypothesis, which is precisely when most of them turn to the experimenter and ask if their hypotheses are correct. If students cannot appeal to the experimenter, then those students who are given instructions to falsify their hypotheses should do better than students instructed to confirm, or follow a control strategy.

## EXPERIMENT ONE

College students were randomly assigned to one of three instruction conditions: confirmatory, disconfirmatory and a control condition. Confirmatory subjects were urged to test their hypotheses by proposing strings that they thought would be correct, disconfirmatory were urged to test their hypotheses by proposing strings they thought would be incorrect, and control subjects were not told about strategies. All subjects worked individually on Wason's 2-4-6 task and were given no feedback concerning whether their hypotheses were right or wrong until the end of the experiment. (For more details concerning the specific instructions and procedures used on this and two related tasks, see Gorman and Gorman, 1984).

### Results.

Results were quite dramatic: 38 out of 40 subjects instructed to disconfirm solved Wason's rule, as opposed to only 19 out of 40 subjects instructed to confirm and 21 out of 40 subjects in a control condition ($\chi^2$=10.76, df=2, p<.005). On the average, 41% of the strings proposed by disconfirmatory subjects were incorrect, as opposed to 22% of the strings obtained by confirmatory subjects and 21% by subjects in the control condition ($F(2,117)$=22.37, p<.001). Disconfirmatory subjects also proposed a string they thought would be incorrect after they had announced a guess significantly more often than subjects in other conditions ($\chi^2$=11.48, df=2,p<.005).

### Discussion

Once experimenter feedback concerning the correctness of hypotheses was eliminated, disconfirmatory instructions greatly improved subject's performance on the 2-4-6 task. Subjects instructed to disconfirm obtained a higher proportion of incorrect strings and were more likely to test a hypothesis with an incorrect string, indicating that their instructions

had helped them avoid the 'confirmation bias' first noted by Wason (1960).

### USING THE 2-4-6 TASK IN THE CLASSROOM

The 2-4-6 task can be used to illustrate falsification in the classroom. An instructor can put the number string '2,4,6' up on the board and ask members of the class to propose other number strings in an effort to guess the rule. As students propose strings, the instructor should write each string on the board and put a Y or an N next to it to indicate whether it conforms to the rule or not. Students should be asked to say why they chose each string. This encourages everyone in the class to think about problem-solving strategies. Tell students to raise their hands any time they think they know what the rule is. When someone proposes a solution, don't stop — urge the class to test it until the majority are satisfied the correct rule has been found. Then ask the class to write down what strings were most helpful in guessing the rule. The role of incorrect strings should become apparent to students as they discuss what they wrote.

The author has done this kind of exercise successfully in classes with from twelve to eighty college students. Some of his educational psychology students have used it successfully in junior high school and high school classrooms and it may be simple enough to be used in elementary school classrooms.

### EXPERIMENT TWO

Would the results obtained on the 2-4-6 task generalize to other tasks and situations? To find out, the present author conducted an experiment using another task explicitly designed to model scientific reasoning. Romesburg (1979) discussed how to use the card game "Eleusis" to teach students about scientific inquiry. As he put it, "For beginning students who have not yet had any science, Eleusis is a training ground for bringing science concepts relegated to the blackboard into action" (Romesburg 1979, p. 607). Briefly, players try to guess a 'rule' the dealer has in mind by playing cards; the dealer tells players whether each card is right or wrong (Gardner 1977). The cards are laid out in a sequence so players can see which cards were right and which were wrong. An example of a simple rule (where H=hearts, C=clubs, D=diamonds and S=spades):

| | | | | | |
|---|---|---|---|---|---|
| **10H** | **5C** | **9H** | **KS** | **2H** | **1S** |
| | **JC** | **3D** | | | |
| | | **4H** | | | |

The top line of cards is correct. The lines of cards going off at right angles were incorrect when played **after** the correct card above them, i.e., the three of diamonds and the four of hearts were incorrect when played **after** the nine of hearts. The rule in this example is alternating colors.

The present author designed an experiment to compare the performance of college students using confirmatory and disconfirmatory strategies on Eleusis. The students worked in groups to discover four Eleusis rules designed by the experimenter. The rules were:

1. Adjacent cards must be separated by a difference of one.
2. Adjacent cards must be separated by a difference of less than three.
3. Odd and even cards must alternate.
4. Cards must alternate either in terms of parity (odd vs. even) or color (red vs. black) or both.

Students were arranged in groups of four. Each group was given one of three sets of strategy instructions: confirmatory, disconfirmatory or a strategy that combined elements of both. Confirmatory groups were urged to test their hypotheses by trying to play cards that should be correct; disconfirmatory groups were urged to test their hypotheses by trying to play cards that should be incorrect; combined groups were urged to discover hypotheses by trying to play correct cards until they had a hypothesis, then testing that hypothesis by playing cards that should be incorrect.

As expected disconfirmatory groups did significantly better than confirmatory or combined groups. The most marked differences in performance occurred on the later, more difficult rules. Every disconfirmatory group solved rule three,

as opposed to only one confirmatory group, and three quarters of the disconfirmatory groups solved rule four, as opposed to one-quarter of the groups in other conditions.

The success of disconfirmatory groups is explained by the fact that they deliberately played more incorrect cards. On the fourth rule, for example, there are dozens of ways to get a card right but it requires deliberate effort to get one wrong: only an odd card played after an odd card of the same color or an even card played after an even card of the same color will be incorrect. Disconfirmatory groups were more successful on this rule because they falsified their hypotheses more often than groups in other conditions: they played incorrect cards 42% of the time on this rule, as opposed to 29% for combined groups and 21% for confirmatory. In fact, on every rule but the first, disconfirmatory groups played significantly more incorrect cards than groups in other conditions.

**Discussion**

This experiment demonstrates that falsification can be translated into a simple problem-solving strategy that college students can use to discover Eleusis rules. Those groups that persistently attempted to falsify their hypotheses were the most successful. These results, therefore, replicate those obtained on the 2-4-6 task and suggest that the value of falsification is not limited to a single task or situation. Disconfirmatory subjects on the 2-4-6 task proposed incorrect strings 41% of the time, and disconfirmatory groups proposed the same percentage of incorrect cards on their Eleusis rules; in both cases, persistent attempts to falsify lead to superior performance.

## USING ELEUSIS TO TEACH FALSIFICATION

The author regularly asks his Educational Psychology classes to work together in groups to discover Eleusis rules. Instead of giving students instructions that tell them what strategy to use, they are encouraged to think about what they are doing as they tried to solve each rule, exchanging ideas and taking notes.

Typically, rules 3 and 4 in the experiment above are used. After the groups either discover the 'odd-even' rule or give up, all are told the correct solution and asked to discuss how to improve their problem-solving process before attempting an additional, more difficult Eleusis rule. (Most groups, given adequate time, will solve this rule.)

In their group discussions, students began to discover the value of trying to play incorrect cards. As one student wrote at this stage, "We had theories, only to find that one card 'shot' the theory. But just as there is a silver lining behind every cloud, it rid the excess clutter and brought us closer to the rule ... we eliminated what the rule **couldn't** be to the point where there was only one rule that it **could** be." This student realized that it is not discouraging to see a theory 'shot down'; on the contrary, this means that the group is one step closer to the correct rule.

The students then employ the insights they gained from the first rule to solving the second. After enough time has been spent on the second rule, the whole class discusses what strategies were helpful in discovering the rule. Invariably, someone mentions trying to get cards wrong or trying to disprove ideas; at this point, the author presents Popper's falsification, using the students' performance on Eleusis as an example. Other ideas come up as well: students talk about the role of competition in science, about the advantages and disadvantages of group versus individual problem-solving and about whether strategies that work on a simple problem like Eleusis will work in the real-world of science, where the 'rules' if they exist, are not simple.

Students enjoy working on Eleusis and find it a valuable experience. As one student commented recently, "I think that working on Eleusis was an excellent learning experience — especially doing it two separate times. I think after the first time we were able to talk about our approaches and then when we did it again it really made the whole process better. I will definitely incorporate it into one of my own science classes in the future."

## FALSIFICATION AND ERROR

Working scientists are acutely aware that a single experimental result may be due to chance, even when the experimenter has tried to be careful about procedures. Therefore, a theory is never falsified by a single experiment. For example, the first experimental test of Einstein's theory of special relativity apparently disconfirmed it, yet Einstein did not abandon his theory even though the experiment was conducted by the eminent physicist Walter Kaufmann and even though "Einstein had to acknowledge that there seemed to be small but significant differences between Kaufmann's results and Einstein's predictions. He agreed that Kaufmann's calculations seemed to be free of error, but 'whether there is an unexpected systematic error or whether the foundations of relativity theory do not correspond with the facts one will be able to decide with certainty only if a great variety of observational material is at hand'" (Holton 1973, p. 235).

Further research supported Einstein's theory, of course, and it was eventually discovered that a procedural error caused Kaufmann's result. But the point is, Einstein knew that a single experiment could not disconfirm his theory; he would have only been concerned if 'a great variety of observational material' raised problems for special relativity.

In Eleusis and the 2-4-6 task, however, a single 'experiment' does disconfirm a theory. For example, if a subject guesses that the rule is 'red-and-black cards must alternate' and a black card is correct after a black card, the subject knows his or her theory has been disconfirmed. But what would happen if the same subject knew that there might be some errors in the feedback he or she was receiving?

## EXPERIMENT THREE

To investigate the effects of the possibility of error on disconfirmatory reasoning, the present author modified the design used in Experiment Two and ran a third experiment (Gorman 1986). Each of twenty-four groups of four introductory psychology students was randomly assigned to one of three instruction conditions: disconfirmatory, confirmatory or a control strategy. Strategy instructions were identical to those used by Gorman et al. (1984) except that a control strategy was substituted for the combined strategy used by Gorman et al.. Control groups were urged to test their guesses by proposing any cards they thought would give them information about the rule.

The second rule used by Gorman et al. was eliminated, to allow extra time for reading the error instructions. After subjects had completed the first rule, they were told there was a 0-20% possibility that a string would be classified erroneously, i.e., if it were actually correct, it would be classified as incorrect and vice-versa. Experimenters used random-number generators on calculators, consulting them every time a card was played to determine whether or not it should be erroneously classified.

If fact, there was not error: subjects were given accurate feedback on every trial. The point of the experiment was to assess the effect of the mere possibility of error. Subjects indicated where they thought errors had occurred by flipping cards over.

### Results

There were no significant differences across strategy conditions, in terms of correct solutions. Only five groups solved Rule 1, only four solved Rule 3 and none solved Rule 4. (Recall that Rule 2 was eliminated for this experiment.)

While performance in both this experiment and the previous one was similar on Rule 1, success rates for Rules 3 and 4 were much lower under error conditions, particularly for disconfirmatory groups. While all eight disconfirmatory groups solved Rule 3 in Experiment Two, only two solved the same rule in Experiment Three. Disconfirmatory groups also did not obtain significantly more incorrect cards than groups in other conditions.

### Discussion

Only one disconfirmatory group had any error cards remaining at the end of the odd-even rule. Five of the seven other

disconfirmatory groups failed to solve this rule, even though they realized that there was no error. Four of these groups proposed rules involving a difference of one between adjacent cards and did not make sufficient attempts to disconfirm their hypotheses, in part because they were so obsessed with making sure there were no errors in the data. The two successful disconfirmatory groups had to combine a strategy of disconfirmation with systematic replication of situations in which apparent disconfirmation occurred. When error is possible, falsification has to be combined with replication (see Lakatos 1978, p. 24, for a similar argument).

## INCORPORATING ERROR INTO CLASSROOM SIUMLATIONS

I have combined Eleusis with the error instructions from Experiment Three to create a classroom simulation of the effect of error on disconfirmation. The format is very similar to the Eleusis demonstration described above: students work together in small groups on the odd-even rule while an instructor walks around, checking a calculator for errors. I have used this simulation successfully with Forestry graduate students, as well as undergraduates in psychology.

A typical undergraduate classroom group performs much like the experimental groups. For example, one such group began by going from Ace to King in sequence, assigning errors to any cards that did not fit the pattern. After they reached the King, one student said, "We've got to figure out a way to go about this. We're pretty haphazard." They decided to systematically eliminate the possibility that the rule involved color by playing four Aces of different colors and suits after the King. When all the Aces were wrong, they correctly concluded that the rule did not involve color, but incorrectly concluded that only a Queen could follow a King. Like many of the experimental groups, they ended-up guessing that the rule involved differences of one between adjacent cards; systematic replication took up so much of their time and energy that they made insufficient attempts to disconfirm their guesses. It is heartening to note that Forestry graduate students showed greater sophistication, systematically developing and testing alternate hypotheses that led them closer to the correct rule.

Overall, students comment that the possibility of error forces them to become more systematic, to replicate in an effort to eliminate alternate hypotheses. They are less likely to discover the value of disconfirmation when simulation includes error. Therefore, as a follow-up exercise the instructor should tell the groups that there was no error on the rule just tried, and ask them to continue to work on it in the absence of error. Students will usually begin to disconfirm more. The class can discuss how it felt to work under error and no-error conditions. Typically, the students complain about how frustrating it is to have to be constantly aware of the possibility of error; it means that they can never be sure a guess is right. But students admit that the exercise demonstrates why falsification must be combined with replication in science, and why it is so tempting to stop falsifying after a clear pattern has emerged from the haze of possible errors.

Even more realistic and sophisticated simulations can be constructed. I have incorporated actual 20% error into classroom simulations, and found that groups correctly identified where most of the errors occurred. Ryan D. Tweney told me how he split a graduate psychology class into groups, each group working on its own Apple computer in an effort to solve an extremely complicated rule (see Mynatt, Doherty & Tweney, 1978, for a description of the task). Eventually, some groups began to cheat, trying to surreptitiously observe others' experiments. One subject broke-off from his group and tried to solve the rule on his own because he felt the group was following a poor approach. In other words, students began to discover things about the emotional as well as the rational aspects of science. This class experienced firsthand how competition affects falsification.

## CONCLUSION

As Lunetta and Hofstein (1981) point out, a major advantage of simulations is that they allow the instructor to model only those aspects of reality that are essential

to his or her instructional goals and eliminate irrelevant features. Eleusis and Wason's 2-4-6 task eliminate much of the ambiguity and complexity of real scientific problem-solving; it is much harder to falsify a scientific theory than an Eleusis rule. But that simplicity is also an enormous advantage — it permits students to discover the failure of falsification inductively, in a short time. An instructor can add elements like the possibility of error to the simulation to help students discover the importance of combining falsification with replication.

However, as Bright, Harvey and Wheeler (1983) showed in a study of the effect of Mastermind on students' reasoning skills, games alone are not sufficient to teach students scientific logic. One of the lessons of recent research using the 2-4-6 task is that, in order to falsify effectively, students must have a mental representation of the problem that tells them where to look for disconfirmatory evidence (Gorman, Stafford and Gorman 1987). It is not enough to know that one must falsify; one must know how. In science, that 'know-how' comes from extensive background knowledge in a particular field, be it forestry, chemistry, or physics.

Therefore, to make simulations effective in the science classroom, they must be combined with laboratory or field experiences. Students can work together first on simulations like the 2-4-6 task or Eleusis, then be reminded of what they learned from the simulations as they come up with results in their forestry laboratory. They should brainstorm alternate explanations for the results obtained, keeping the possibility of error in mind, then design further experiments or field studies that might falsify their current hypotheses (see Platt, 1964, for a discussion of how this approach works in physics).

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the techniques of artificial intelligence to discovering hypotheses (Langley, et al 1987). The consensus at this point is that there are no right or wrong ways to achieve Discovery; in essence, anything goes!

Although anything goes in Discovery, the resulting hypotheses must satisfy certain criteria. One of these is the testability criterion. A hypothesis is testable if it is sensitive to comparisons with empirical evidence. If the comparison is favorable, the outcome is corroboration; if the comparison is unfavorable, the outcome is contradiction or disproof. Corroboration is used in the sense of supporting but not conclusively proving. The testability criterion has two parts: if the hypothesis is correct, corroborating evidence must be detectable, and if the hypothesis is false, contradicting evidence must be detectable. Note that some hypotheses do not satisfy both parts of the criterion. Universal hypotheses such as 'all swans are white' can only be disproved, while existential hypotheses such as 'there are signals that travel faster than the speed of light' can never be disproved. The degree of testability of most hypotheses is much more subtle than these examples illustrate, and must be determined before experimentation.

For many hypotheses the degree of testability depends on experimental design. In testing a statistical hypothesis, choices are made for the significance level, say .05, a test statistic, and the corresponding critical value. There is confidence that if the hypothesis is correct there is a 95 percent chance of detecting corroborating evidence. Thus, half the testability criterion is satisfied, in probability, simply by choosing a significance level. Satisfying the other half of the criterion is usually not so simple. First, it is necessary to state what would be sufficient evidence to disprove the hypothesis, and then determine the chances of detecting those conditions if they exist. This is the matter of statistical power. If the probability of detecting the conditions is very small, then the hypothesis is not fully testable. The reporting of nonsignificant results from experiments with low statistical power has been called "scientific fakery" (Anonymous 1985a).

## JUSTIFICATION

Justification strategies may be classified with respect to two factors, logical intent and number of hypotheses (Figure 1). The logical intent of Justification strategies has traditionally been corroboration. Only since the influential

| Logical intent | Number of hypotheses: 0 | 1 | 2+ |
|---|---|---|---|
| Proof | | | |
| Corroboration | Induction/ Retroduction | Hypothetico-Deduction | Multiple Hypotheses |
| Contradiction | | Research Programs | |
| Disproof | | Falsification | Strong Inference |

Figure 1. Justification strategies.

# A SURVEY OF RESEARCH STRATEGIES

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**Abstract**. Two features of science which distinguish it from non-science are its unique goal and its unique method. The method of science consists of three major activities: Problem identification, Discovery, and Justification. Problem identification is briefly discussed with respect to the Kuhnian concept of paradigm and with respect to Leary's measure of the productivity of scientists.

The endpoint of Discovery is the formulation of one or more hypotheses. A critical attribute of hypotheses is their testability. Fully testable hypotheses may be corroborated or disproved on the basis of evidence. A high degree of statistical power is necessary to assure the full testability of some hypotheses.

Justification has three components: Research Strategy, Empirical Test, and Inference. Research strategies may be classified with respect to two factors: logical intent and number of hypotheses. The syllogistic structure and key features of seven research strategies are discussed in the context of the two factor classification. A principle of modern science is that inferences be made only on the basis of tests consisting of comparisons of hypotheses or their predictions with empirical data. The strength of an inference based on an empirical test depends on the syllogistic structure of the corresponding research strategy.

Mario Bunge (1967) asserts that science has a unique goal and a unique method that distinguish it from non-science. He states that the goal of the factual sciences is "to build conceptual mappings of the patterns of facts - i.e., factual theories." With respect to method, he asserts that "the scientific method is a mark of science, ... no scientific method, no science." In discussing the components of scientific method, Hans Reichenbach (1938) emphasized the distinction between the context of Discovery and the context of Justification. The starting point for Discovery is an identified problem or gap in the current state of knowledge, and the ending point is one or more hypotheses, models, or solutions proposed to solve the problem or fill the gap. The starting point for Justification is the set of hypotheses, models, or solutions, and the ending point is a justifiable inference concerning them. A brief survey of Discovery and Justification strategies follows.

## DISCOVERY

One of the important distinctions between Justification and Discovery is that there is a logic of Justification, while Discovery has usually been considered a creative enterprise for which no logic can be constructed. Strategies that have been used to discover hypotheses include the following:

- Trial and Error
- Systematic Search
- Serendipity
- Inspiration
- Illumination of the well-prepared mind
- Analogy
- Derivation from Theory
- Induction
- Retroduction

The latter two, Induction and Retroduction, are frequently considered Justification strategies, but, as will be discussed later, it may be more proper to consider them Discovery strategies. A recent innovation, which may ultimately lead to a logic of Discovery,

hypotheses (Langley, et al 1987). The consensus at this point is that there are no right or wrong ways to achieve Discovery; in essence, anything goes!

Although anything goes in Discovery, the resulting hypotheses must satisfy certain criteria. One of these is the testability criterion. A hypothesis is testable if it is sensitive to comparisons with empirical evidence. If the comparison is favorable, the outcome is corroboration; disproved, while existential hypotheses such as 'there are signals that travel faster than the speed of light' can never be disproved. The degree of testability of most hypotheses is much more subtle than these examples illustrate, and must be determined before experimentation.

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| Disproof | | Falsification | Strong Inference |

Figure 1. Justification strategies.

work of Karl Popper (1968) have negation oriented strategies been seriously considered. Although the categories of logical intent are shown here in their natural order, they are discussed in the chronological order of their development. Strategies that begin without hypotheses provide little justification and probably should be considered Discovery strategies. Single and multiple hypotheses strategies, particularly with a negation oriented logical intent, provide powerful alternatives to traditional strategies. The strategies resulting from combining the categories of logical intent with zero, one, or multiple hypotheses are described in terms of their key features.

**PROOF**

The Greeks believed that truth in the form of universal structures existed despite the variability they saw in actual observations. Greek scientists sought to discover these truths by way of intellectual or rational insight. Well into the 15th and 16th centuries, disciples of Greek science ridiculed attempts to reconcile knowledge with observation. For them genuine knowledge of the natural world through empirical science was impossible.

However, with the Renaissance this view changed. By the 17th century Francis Bacon's (1960) *Novum Organum* had become the fundamental treatise on the logic of scientific method. In this work Bacon insisted upon a gradual passage from concrete facts to broad generalizations and upon the use of controlled experimentation, not just observation. The phenomenal successes of Newton who used and extended Bacon's methods firmly established empiricism as a fundamental principle of science.

However, in his exaltation of induction and experiment, Bacon held that general laws could be established with complete certainty by using these almost mechanical processes. It was not until David Hume's (1966) Treatise of Human Nature in the 18th century that the myth of scientific proof by inductive methods was completely debunked. With empirical and experimental methods in hand and a clear understanding of the impossibility of proof by inductive methods, modern science emerged.

**CORROBORATION**

As stated earlier, corroboration is used in the sense of supporting but not conclusively proving. Corroboration strategies are loosely based on a valid, logical argument form called Modus Ponens. The essence of Modus Ponens is that if the antecedent, p, of a conditional proposition is established, then the consequent, q, must logically follow. Scientific corroboration strategies, unfortunately, usually attempt to establish the consequent and then imply the antecedent. They are guilty of what Copi (1967) calls the "Fallacy of Affirming the Consequent". Thus, corroboration strategies do not follow a valid argument form, and their conclusions are not necessarily valid. Closer examination of specific corroboration strategies clarifies the issue.

**0 HYPOTHESES - Induction**: Induction might be defined as the ever increasing accumulation of hard facts, F, which can be understood by means of tentative generalizations, G. A key feature of induction is that the facts are acquired before the generalizations are formulated. The generalization is usually not tested on data other than that from which the generalization has been formulated, and it is usually uncertain if the second part of the testability criterion has been satisfied. Successfully meeting the second criterion would seem to be mostly a matter of chance with Induction. Carl Hempel (1966) states:

> Scientific knowledge is not arrived at by applying some inductive inference to antecedently collected data, but rather by inventing hypotheses as tentative answers and then subjecting them to empirical test.

Induction would be better considered a Discovery strategy than a Justification strategy.

**0 HYPOTHESES - Retroduction**: Hanson (1958) describes retroduction as the following sequence:

1. A surprising phenomenon, P, is observed,
2. P would be explainable if hypothesis H were true
3. Therefore, there is reason to think H is true.

Retroduction, like induction, is guilty of affirming the consequent. Also, like induction, the phenomenon is observed before the hypothesis is formulated, and so it remains uncertain if the second part of the testability criterion is satisfied. Retroduction would also be better considered a Discovery strategy.

**1 HYPOTHESIS - Hypothetico-Deduction**: Hypothetico-deduction is used as a strategy for corroborating single hypotheses. The hypothesis, H, is discovered by any means available to the researcher. From the hypothesis, H, a prediction or deduction, D, is derived, which is then compared to empirical evidence. The evidence is acquired after the hypothesis is stated and therefore should be appropriate in kind and amount to satisfy the second part of the testability criterion. Nevertheless, Hypothetico-Deduction is still a corroboration strategy and, as such, suffers from an invalid argument form.

**2+ HYPOTHESES - Multiple Hypotheses**: In addition to an invalid argument form, single hypothesis strategies also may suffer from scientists' attachment to their hypotheses. The moment a scientist offers an apparently satisfactory hypothesis it becomes that scientist's personal possession. Hanson pointed out that even when scientists are free from such attachments, observations are generally not free from observer bias. An example (Figure 2) due to Hanson and also discussed by Brown (1977) demonstrates that the response of an observer's senses to external stimuli may depend on the hypothesis in mind. Furthermore, Hanson contends that it is not possible for multiple responses to occur simultaneously. Lack of objectivity may be a serious problem when attachment and observer bias occur.

These difficulties may be partially avoided by using the "method of multiple hypotheses" as proposed by Chamberlain (1897). With this strategy, each problem is surrounded with hypotheses and a series of experiments is performed to distinguish among them. Chamberlain points out that this strategy "distributes the effort and divides the affections." The structure of the argument is essentially a series of Hypothetico-Deductive arguments and therefore still suffers from an invalid argument form. However, when multiple hypotheses are used, scientists may perceive the same observations from multiple perspectives.

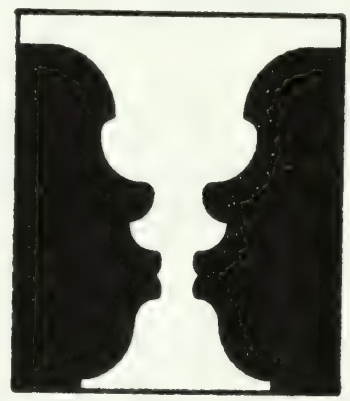

Figure 2. A vase or faces kissing?

**DISPROOF**

Karl Popper (1968) suggested that the problem of the invalidity of the induction argument could be avoided by shifting from corroboration strategies to disproof strategies. He argued that conclusive disproof is possible because it takes only a single counterexample to disprove a hypothesis. The basis of disproof strategies is the valid argument form, Modus Tollens. The essence of this argument is that if the negation, ~q, of the consequent, q, of a conditional proposition is established, then the negation, ~p, of the antecedent, p, must logically follow. Although corroboration strategies do not follow a valid argument form, disproof strategies do. Popper argues that science advances by disproof because hypotheses are conclusively eliminated from further consideration. For Popper, the only results regarded as corroborating

evidence for hypotheses are new and interesting failures to detect counterexamples where they would be most expected to occur.

**1 HYPOTHESIS - Falsification**: The falsification strategy requires a clear statement of the hypothesis and a clear statement of the conditions under which the hypothesis would be abandoned. The objective is to disprove the hypothesis by acquiring evidence establishing the falsifying conditions. Just as there is a clear distinction between the objectives of corroboration and falsification strategies, there is also a clear distinction between their experimental designs. Corroboration designs must provide for acquiring both supporting and contradicting evidence to satisfy both parts of the testability criterion. Designs for falsification experiments concentrate resources to provide maximal opportunity to detect counterexamples. If the conditions are detected, conclusive disproof is established. Failure to detect the conditions is construed as corroborating evidence because the hypothesis has withstood an extremely rigorous test.

**2+ HYPOTHESES - Strong Inference**: The problem with falsification, as Platt (1964) pointed out, "is that disproof is a hard doctrine." It is not easy to continually place hypotheses representing years of labor onto the cutting edge. This difficulty can be partially alleviated by using Chamberlain's method of multiple hypotheses. In fact the full potential of the multiple hypotheses concept is not realized until it is combined with a disproof intent and a logical tree structure. Platt dubbed this strategy "strong inference". The steps of the strategy are as follows:

1. Surround the problem with an exhaustive set of hypotheses whose deductions are mutually exclusive.

2. Arrange the hypotheses into a tree structure on the basis of similar and dissimilar features,

3. Perform falsification experiments at branching points to eliminate one branch or the other.

Consider the problem of determining the cause of the Cretaceous-Tertiary extinction (Why did the dinosaurs die?). The following list of hypotheses, although not complete, illustrate the strategy:

Oceanographic changes
Atmospheric changes
Climatic changes
Geo-magnetic reversal
Solar flares
Meteors or comets
Nemesis: a solar companion
Supernova
Solar movement: moving through galactic arm

This completes the first step, surrounding the problem with hypotheses. If the set of hypotheses is not exhaustive, then the surviving hypothesis may later be falsified itself. If the deductions from the set of hypotheses are not mutually exclusive, then there will be difficulty in falsification at some branching points. The second step is to arrange the hypotheses into a tree structure (Figure 3). This is not necessarily the only tree structure possible. The final step is to distinguish among the hypotheses on the basis of falsification experiments at succeeding branching points beginning at the left.

Walter Alverez, the Nobel laureate physicist, and his son Luis (1980) have reported what they believe constitutes a falsification of the terrestrial branch. They base their assertion on detection of elevated iridium levels at the Cretaceous–Tertiary boundary. They contend that because such levels are unknown on the basis of natural terrestrial processes the cause must be extra-terrestrial. Whether they are right or not, the example illustrates the way the strategy works. Platt attributes much of the recent rapid advances in molecular biology to use of this strategy. When the premises are sufficiently satisfied, the Strong Inference strategy can be a powerful tool.

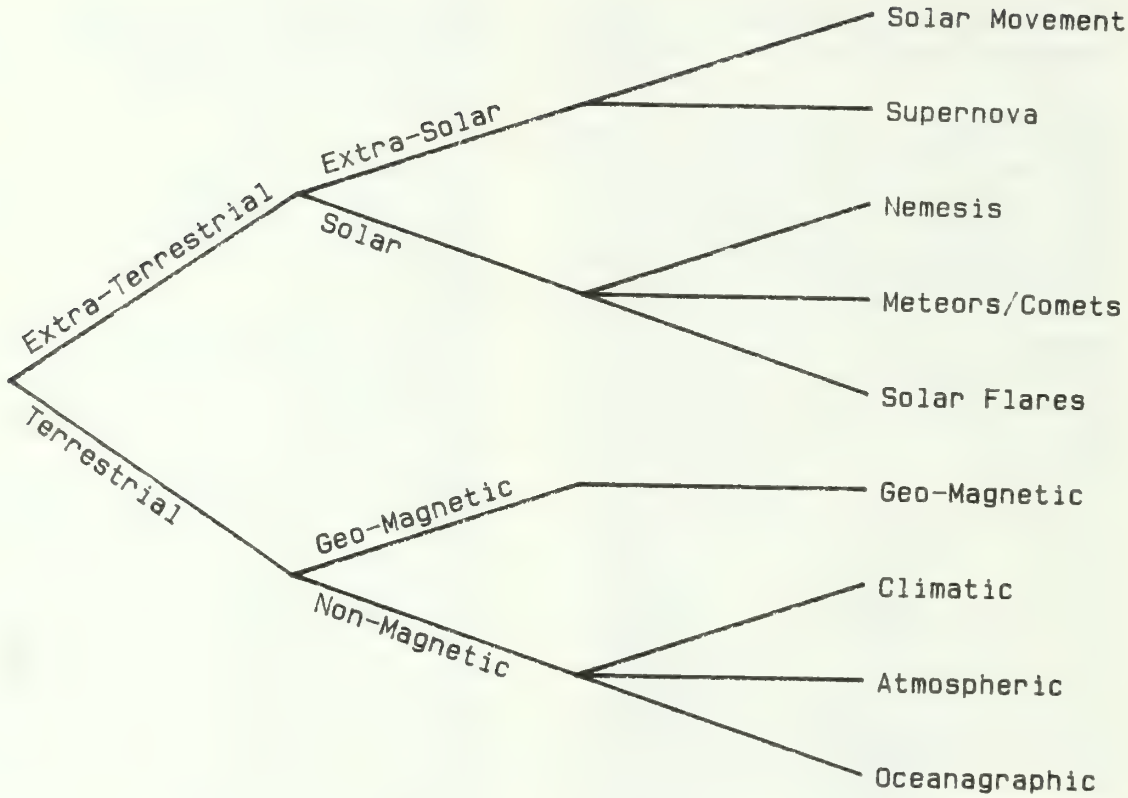


Figure 3. A tree structure for C-T extinction hypotheses.

**CONTRADICTION**

Disproof strategies suffer, in general, from reluctance on the part of researchers to accept their conclusions. Skeptical non-falsificationists are frequently unwilling to ascribe the power of conclusive disproof to Popper's counterexamples. This is particularly true when a favorite hypothesis or an established theory is the candidate for disproof. Non-falsificationists admit the contradiction between the evidence and the hypothesis but relegate such results to the category of anomalies rather than counterexamples.

There is justification for this attitude. Hypotheses are rarely tested in a vacuum. Virtually every test of a hypothesis is actually a test of the hypothesis in conjunction with paradigms, theories, supporting hypotheses, and additional assumptions concerning methodology, instrumentation, and observation. The falsification is of the conjunction and may be attributed to any of the conjuncts. For many reasons it may be appropriate to attribute the falsification to a conjunct other than the basic hypothesis. The history of science abounds with examples of such actions later being justified.

**Research Programs**: In an attempt to shore up Falsification, Lakatos (1980) developed a strategy he called Research Programs. The procedure is to first specify the protected hard core, C, of propositions that are currently considered established. The supporting and/or tested hypotheses, H, are then formulated and the falsifying conditions, ~D, are specified. The falsifying conditions are now seen as the negation of a deduction, D, from the conjunction of H and C. As in Falsification, an experiment is designed and performed in an attempt to detect the falsifying conditions. If such a counterexample is detected, the falsification is attributed to the supporting and/or tested hypotheses, H, not to the hard core, C. Research continues with this hard core as long as progress occurs. The

decision to discontinue the research program or alter the hard core occurs by consensus among scientists working in the program.

As an example, consider the numerous attempts that have been made to measure continental drift. One current method, Very Long Baseline Interferometry or VLBI, uses dish antennas on opposite sides of the Atlantic to record radio signals from the same quasar, an extremely distant and therefore stationary reference point. The differences in arrival times permit precise estimates of the distance between the two receivers. The annual rate at which North America and Europe are separating has been estimated by this method at 2.0 centimeters per year (Anonymous 1985b). Unfortunately, the precision of the VLBI method is only about 2 or 3 centimeters per year. Based on the data, it might be logical to conclude that the rate is not significantly different than zero and that there is no evidence for continental drift. However, VLBI scientists contend that atmospheric interference, bending of the signal in the ionosphere, and the unsteadiness of the Earth introduce noise into the signal that prohibits achieving a precision of about 3 millimeters. In this example, it is clear that the continental drift hypothesis is a part of the protected hard core and that it is actually the instrumentation that is being tested.

The logical intent of the research programs strategy has been labeled contradiction. Logically, it is negation oriented like disproof, but it is less conclusive due to the lack of logical validity for protecting the hard core.

## SUMMARY

Discovery and Justification are different components of scientific method and require strategies with different features. Discovery strategies must satisfy only one demand: they have to work. Justification strategies must satisfy the demands of an imprecise, but fairly well agreed upon logic. Some Justification strategies satisfy these demands better than others. The classification of Justification strategies in Figure 1 and the ensuing discussion are intended to help scientists better distinguish among such strategies and select the appropriate one.

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# THE CONCEPT AND MEASUREMENT OF MULTIRESOURCE SITE QUALITY

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**Abstract**. Conceptual ambiguities and measurement problems have clouded the evaluation of forest lands for the joint production of goods and services. Reduction of resource potentials to a common metric, whether timber site quality or a utilitarian measure of social value (a monitory unit), relies on reifications of resource concepts and unfounded assumptions of equilibrium. The nature of resources as social constructs is fundamental to any assessment of forest site quality, since social purposes define the qualities of forest lands that we attempt to measure. Social purposes are dynamic and, outside certain limits, unpredictable. As a result, site qualities are inherently unstable, and their measurement tends to be imprecise and outmoded. This paper suggests a dynamic, ecosystems based approach to assessing the functional potentialities of forest lands. Multiple functions of forest lands can be best achieved by managing forest ecosystems in accordance with certain structural and functional requirements. Examples of such requirements are provided.

## PROBLEM

Contemporary forest planning necessitates that forest lands be assessed in terms of their capability to produce a wide variety of goods and services. This need is evidenced by resource conflicts in both developed and developing countries. The forester's emphasis on a single good, e.g., timber, has been opposed increasingly by those who favor other goods and services. Social conflicts between advocates for the production of timber, wildlife, fish, scenery, and recreation opportunities in national forests of the Pacific Northwest and Southeast Alaska led to research from which this paper was developed. However, the methodology to address these problems is applicable to any other region of the world where wood production conflicts with other uses. This paper discusses the conceptual and measurement problems involved in assessing the capability of forest land to produce a variety of goods and services. A subsequent paper will compare methods for assessing the productive capability of particular sites (Lee and Clark, in process).

Concepts of "resources", "multiple use", and "site quality" are central to this paper. Yet the meanings of these concepts are poorly understood. Field foresters, forest policy makers, and forest scientists share a universe of discourse in which these concepts are used routinely to simplify experienced reality rather than to analyze difficult questions. Simon (1955) has shown that people employ simple mental models to represent complex aspects of reality. Frustrating experiences arising from complex and intractable aspects of forest land management are made less threatening by imposing simple abstractions. Recent research has gone further in showing that there is a tendency for people to deliberately falsify their experience of "reality" in order to conserve or protect an orderly and "rational" image of the world (Bailey 1983). This is especially true of experience related to inherently complex, dynamic, or threatening circumstances. I assert that much of the ambiguity associated with the forestry concepts of "resources" and "multiples use", and to a lesser extent "site quality", is due to their status as abstractions for falsifying experience — for denying troublesome sources of instability and complexity in forest management.

Ritual utterances of these terms "clears the air" and assuages fears and anxieties that "things are out of control". The purpose of these concepts is clearly not to clarify their meaning as referents for actual objects or events[1]. Most writers

[1]In this paper I will ignore the possible latent sociological functions of such rituals; the sociological literature would suggest that in addition to its manifest

have relied solely on definition of the term "multiple use" as a way to specify its meaning (Leary 1985). Linguistic elaboration, including adding new labels, has prevailed over attempts to identify how the concept can be used to refer to objects and events. Similar reliance on elaborating definitions occupies most of the literature on multiple forest resources. Such definitions conserve common sense meanings and assure orderly interpretations of otherwise problematic experiences. Falsifiying troubling aspects of experience has taken precedence over attempts to use these concepts as instruments for scientific investigation.

The tasks of conceptualization and measurement of multiresource site quality are especially formidable. Forest scientists have made little progress toward adequate scientific formulations because they have not broken away from the common sense discourse in which these problems are generally stated. In formulating this paper I responded to the challenge issued by Rolfe Leary (1981) when he helped initiate the new IUFRO subject group on Philosophy and Methods of Forest Research. Leary suggested that we assess the maturity of forest science and seek to improve the quality of research by 1) becoming "more rigorous in our terminology" (p. 362), and 2) relying on appropriate mathematical formulations. I will address the first criterion by analyzing the meaning of multiresource site quality. Then I will address the second criterion by summarizing an approach we are using to evaluate propositions linking resources to ecosystem structure and processes.

## SPECIFYING MULTIRESOURCE SITE QUALITY

The capability of a forest to satisfy a variety of human wants and needs has generally been assessed by defining a number of resource potentials and reducing these potentials to a common metric. In national forest planning, the U. S. Forest Service first defines the potential for a site to produce timber, recreation, water, wildlife, range, and other resources and then assigns a monetary value to each resource as a means for reducing potential resource outputs to monetary units — a utilitarian measure of social value. A complicated linear programming model, FORPLAN, is used to analyze resource values and prescribe an optimum combination of resources as outputs from an aggregation of planning areas.

An earlier tradition of forest planning assumed that "good" silviculture and timber management would automatically produce multiple resource potentials. Much of this tradition was informed by the conventional wisdom we inherited when European forestry practices were first adopted. There was a tendency to associate forest resource potentials with wood production, thereby assuming that good timber management on highly productive sites would promote resource potentials other than timber (See Duerr and Duerr, 1975, for an insightful discussion of this and other forestry doctrines). As with rhetorical statements about multiple use, "good" forestry was seldom specified, and eventually, requirements for modern forest planning were promulgated to force foresters to become more accountable in preparing forest management prescriptions.

Regardless of these planning requirements, methodologies for land assessment still rely on the conventional wisdom of the forestry community to define the concept of multiple use and its key constituent element—multiple resources. The multiresource "producing power" of the site is ignored almost entirely, or is assumed to be derived by summing the separate site ratings for each resource under consideration; interactions between biological production possibilities are thereby assumed to be insignificant.

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function of conserving a sense of orderly life, ritual utterances may also perform the latent function of maintaining existing power relationships. Hence, an apparent paradox could be resolved by hypothesizing that the existing emphasis on timber production is in part maintained by symbolic displays of the importance of multiple use.

The most advanced efforts at conceptualizing site quality and multiple use have been provided by Leary (1985). I will build upon his efforts by joining these two concepts and incorporating a conceptualization of natural resources provided by Zimmerman (1951). Since the concept of a "resource" is fundamental to both site quality and multiple use, discussion will begin with a review of Zimmerman's contributions.

**Resources as Social Functions**

The conventional use of the term resource is a prime example of what Whitehead referred to as the "fallacy of misplaced concreteness"—the reification of an abstraction. How often have you heard foresters talk about timber, forage, and scenery as if these resources are tangible objects to be found in the forest? Yet when we seek to find these resources, we see trees, grasses and forbs, and configurations of light, sky, mountains, trees and water. Resources are no more tangible than ecosystems; both are social constructs—invented to enable us to gain more from nature.

Zimmerman (1951) rejected the common sense view of resources and substituted the following definition:

> The word "resource" *does not refer to a thing or a substance but to a function which a thing or substance may perform or to an operation in which it may take part,* namely, the function or operation of attaining a given end such as satisfying a want ... the word "resource" is an abstraction reflecting human appraisal and relating to a function or operation (p. 7, original emphasis).

The false impression of resources as things that are static substances, fixed in tangible natural forms, continues to be the greatest obstacle to the advancement of research on forest resources. Large sums of money are spent annually in attempts to describe the biophysical properties of resources for purposes of inventory and management. Research on the beguiling "visual resource" is perhaps the most fascinating illustration of the linguistic capacity resource professionals have for falsifying the complex and dynamic character of experience — in this case the experience is the intangible aesthetic attribution of beauty to nature. Fifty years after Zimmerman first clarified the functional meaning of the resource concept many researchers still cling to the obsolete notions of resources as tangible substances[1]

Greater rigor in the use of the term "resource" demands that it be used as a relational "concept which legitimately belongs to the social scientist" (Zimmerman 1951, p. 10) rather than to the resource specialist. Unlike the tangible objects found in natural systems, resources change unpredictably in response to changes in societal tastes and values or changes in knowledge and technology. New resources emerge and old resources disappear with societal changes such as the invention of new wood processing technologies: scrub hardwoods are becoming a valuable source of raw material for making wafer board, and the market displacement of plywood by wafer board threatens to eliminate the need for large growth peeler logs for plywood stock. Socially defined tastes, values, knowledge and technology are extremely dynamic and, outside certain limits, are largely unpredictable. This makes the task of predicting resource requirements and production capabilities exceedingly difficult for all but short-range (5-10 year) resource planning. Before suggesting how an ecosystem-based approach can partially overcome this

[1]Again, I will resist a sociological analysis of the manifest and latent functions of linguistic conventions that define fixed properties of thing-like resources, but alert the reader to the possible sociological significance of professional forestry rituals involving both research on and management of such "resources". The more sophisticated reader will quickly appreciate the social fact that such naive resource definitions are themselves critical resources for those who manage forests, as well as for those who seek to influence their management.

limitation. I will suggest how the concepts of multiple use and site quality can be joined by incorporating a functional conception of resources.

**Multiresource Site Quality**

Site Qualities and the Resource Concept

The traditional concept of forest site quality concerned the problem of assessing the capability of a site to produce forest growth. Leary (1985) draws an analogy between a forest as a habitat for animals and a site as an environment for the forest. In each case he linked a "field" of influences (vegetation complex or soil/atmosphere complex) to a "test body" (animal or tree) through the latter as a "testing device" for "sensing" the "field" of influences. Emphasis on the performance of an organism in a given environment is preferred when knowledge of the workings of a soil system or ecosystem are inadequate for purposes of predicting how an organism will respond.

However, use of the organism as the "testing device" requires that responses to sociological and other contextual influences be separated from responses to vegetation or the soil complex. Attention should be focused on the immediate functional requirements for vegetative or the soil environment, while the influences of factors such as population density and reproduction levels need to be eliminated. Consequently, Leary (1985) notes that "the key individual in assessing the 'animal producing poser of the forest' is not so much the animal ecologist as the animal physiologist" (p. 3.25). Habitat quality is indicated by qualitative, physiologically-related attributes such as the size of horns in Dall sheep (Bunnell 1978) instead of the total number of animals in a localized population.

The analogy between habitat and site quality can be productively extended to a human-centered assessment. Biotic and abiotic objects in the natural environment constitute the "field" and the "test body" is the particular social function served by these objects. The resource concept is appropriate for specifying the relationship between social functions or operations and the natural objects that make them possible. At this point I suggest modification and extension of the resource concept to cover function relationships between animals and their habitats, as well as between forests and their environments. Hence, we can appropriately talk about resources for trees, animals and humans.

Just as with trees and animals, an organism-centered approach to assessment requires that attention be focused on identifying how natural objects serve particular functions in human societies. The influence of sociological and other contextual factors on these functions needs to be separated from the influence of the operational environment afforded by forest ecosystems.

Defining Resource Site Quality

The term "resource site quality" will be used generically to refer to the capacity of the biophysical environment to produce objects and their attributes that are required in order for natural organisms or human society to function. "Site" will denote a space of ground to be occupied by vegetation, organisms or human artifacts that perform essential functions for human society or nonhuman organisms. In the case of resources for trees (not timber), a moist and fertile soil is a requirement for rapid biological growth. These site qualities are essential for the physiological processes involved in rapid tree growth.

Similarly, timber resources for humans may be trees of sufficient height, girth, and freedom from defects to provide wood required for large construction timbers. Only those trees with attributes that enable them to yield timbers can perform this function. But, in addition to their attributes, these trees must be accessible and affordable before they can become timbers, and there must exist a body of knowledge, technology, and labor appropriate for extracting them from nature, transforming them into timbers, and assembling them into structures. However, timber site quality would be limited to relevant objects and attributes found in a delimitable space of ground that is capable of supporting tree

growth. In addition to the biological possibilities for growing suitable trees, accessibility, including surface conditions (swamps and rocks) and topography might be considered as relevant objects and attributes. The other conditions might also influence whether a timber-producing industry will prosper, but they are irrelevant for assessing site qualities. Let me now extend the analogy by linking site quality to multiple use.

**Site Quality and Multiple Use**

The conventional view of resources as tangible things has informed almost all discussion of multiple use. Considerable progress in conceptualizing multiple use was made by Leary (1985) when he considered "resource" to be a relational concept linking populations of natural objects with populations of prospective users. He also considered location and time as critical variables when reformulating multiple use, and included in a multiple use system the managers for timber, wildlife, range, and other resources. Human users were distinguished from non-human biological users, and abiotic and biotic populations of natural objects were treated separately. Multiple use was operationally defined in terms of relations between sets of biotic and abiotic natural objects, human and non-human users, managers, locations, and times. Multiple use statements were said to map the Cartesian products of these sets.

Leary (1985) states this as a propositional function that maps objects into statements—thereby achieving a formulation that conceives of multiple use in terms of its referents:

$$MU: P_b \times P_a \times M \times U_b \times U_h \times L \times T \rightarrow S$$

where:

MU designates the concept (predicate) "multiple use"

$P_b$ denotes the set of biotic populations, i.e., trees, not timber; animals, not wildlife; shrubs, not brush, etc.

$P_a$ denotes the set of abiotic populations, e.g., water bodies (streams and lakes, etc...), natural "mineral licks", etc.

M denotes the set of managers

$U_b$ denotes the set of populations of biotic users of biotic and abiotic natural object populations

$U_h$ denotes the set of populations of human users of biotic and abiotic natural object populations

L denotes the set of locations

T denotes the set of times

S designates the statements that use the concept

$\times$ denotes the mathematical symbol for the Cartesian product of sets, and

$\rightarrow$ designates mathematical mapping.

Improvements upon Leary's formulation can be made. Leary was not entirely successful in removing "resource" as one of the referents of multiple use. Although the resource concept was appropriately replaced by populations of objects and populations of users, Leary did not consider sufficiently the possibility of functional linkages between these sets. Analysis of multiple use can be simplified substantially by reintroducing the resource concept.

The set of managers most appropriately represents these functions in the present formulation. Resource managers naively act as apologists for particular social functions because, as has been explained above, they conform to linguistic conventions which lead them to focus on certain aspects of experience and to deny other aspects. Managers can be defined as resource agents who manipulate natural systems to facilitate some social functions and to inhibit others. Thus, by including managers, Leary unknowingly reintroduced the resource concept.

The need to consider relational concepts as central to multiresource site quality has led us to suggest a reformulation of Leary's propositional function. It is summarized here so that concepts may be clarified by comparing competing formulations. A different formulation is

suggested for purposes of measurement — to be discussed in the following section.

MU: $E \times P \times C_n \times C_h \times D \times M_r \times L \times T \rightarrow S$

where:

E denotes the set of populations constituting the abiotic environment, e.g. climate, soil, streams, etc.

P denotes the set of populations of primary producers, e.g., the photosynthetic "engine".

Cn denotes the set of populations of non-human consumers, e.g., grazers, browsers, fructivores, etc.

$C_h$ denotes the set of populations of human consumers, e.g., wood gatherers, berry gatherers, mushroom gatherers, fishermen, recreational hikers, etc.

D denotes the set of populations of detrital feeders, e.g., fungi, molds, etc.

$M_r$ denotes the set of populations of resource managers who purposefully manipulate all of the other sets to promote certain social functions, and other sets are as above.

The logic of sets and their possible relationship is specified more clearly by using the theory of ecosystem structure and process to reformulate the propositional function. Inclusion of human actors (collectivites, groups, or individuals) as consumers and managers makes it apparent that we can broaden the referents of the multiple use concept to include both "resources" and "resource relationships"[1]- two useful concepts eliminated in Leary's formulation. Most importantly, by extending the concept of resources to represent functional relationships between non-human objects, we are able to talk about a "chain" or "web" of "resource relationships" — even further broadening the referents of multiple use.

Multiple use is linked to site quality through the resource concept. Multiresource site quality assessment involves evaluating the capacity of a forest site to facilitate a variety functions involving both human and non-human organisms. The resource concept is fundamental because the first step in any such assessment is to ask, "For what purposes (functions) am I evaluating a forest site?" Site quality assessment is a resource driven process.

Assessment methods for several individual resources have been developed and continue to be refined. The above discussion of timber site quality and wildlife habitat illustrates such methods. However, assessment involving more than one resource is only now emerging. The function concept of resources, when coupled with the reformulated concept of multiple use, provides a rigorous terminology for developing such methods.

## MEASURING MUTLIRESOURCE SITE QUALITY

We are pursuing the further development and refinement of one such approach in our work in the Pacific Northwest. Our purpose is to link specific resources to the changing state of forest ecosystems as they recover from disturbance (especially harvesting).

There is an important reason for using an ecosystems based approach. Societally-defined resources are inherently unstable. As a result, their measurement tends to be imprecise and frequently outmoded. Even such relatively stable technologies as sawmilling change so rapidly that timber inventories based on utilization standards from the 1960's are

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[1]"Resource relationships" are central to multiple use concerns because they underly most user (consumer) conflicts. Competition between social functions may occur indirectly in the form of "resource conflicts" as well as directly in market processes, interpersonal conflict, or political and legal conflict. Incompatible uses for a tree, such as timber versus a nesting site for eagles, illustrates a "resource conflict", whereas crowding of the tree by other vegetation would constitute a "conflict" between natural objects.

inadequate for present conditions. Recreation tastes and preferences have changed even more rapidly with the adoption of off-road vehicles and other forms of modern technology.

Methods for simulating the dynamic behavior of forest ecosystems will provide a means for predicting populations of objects and attributes that facilitate a wide variety of functions. Emphasis on site conditions that support resource functions rather than on resources themselves will assure a more durable and precise basis for long-term multiresource assessment. Such ecosystem models can be developed and refined through cumulative research efforts, while resource studies often have a very limited useful life. Less sophisticated methods can be used to link resources to the state of forest ecosystems.

We are presently evaluating the use of a systems dynamic model that simulates ecological processes to provide a projection of resources in biologically possible combinations. The system, developed by Boyce (1977, 1980), is named DYNAST — acronym for "Dynamically Analytic Silviculture Technique". DYNAST consists of a core ecological model that simulates successional recovery following a disturbance (in this case, harvesting). Input to this core model consists of manager-induced interruptions in the normal recovery process: silvicultural controls of rotation length, harvest rate, size of harvest units, and the type and rate of species conversion. Output from the core consists of a simulation of forest structure at various times in the future: proportion of the forest in specific age/species classes, stand area, and vegetation types.

The multiresource capability of DYNAST is contained in modular algorithms for specific objects, attributes, or resources: wildlife, timber, scenery, recreation, water, forage, and so forth. A module can be written for any resource, object or attribute that can be linked directly to forest structure. All resources or objects are treated equally, and are constrained only by what is ecologically possible. In this sense, the system does not consider conflicts between resources or consumers. Hence, DYNAST is ideally suited for assessing the qualities of a forest site for which silvicultural practices are the disturbances.

Most of our research focuses on the development of modules for specific resources. The algorithms contained in each module enable us to "measure" how each resource will be affected by specific silvicultural practices — thus providing an assessment of how relevant qualities of a site are altered by various practices.

Existing literature is the primary source for assembling an inventory of propositions linking the specific resources to forest structure. Where existing propositions are lacking, in conflict with one another, or vague, original research is undertaken to develop and/or test propositions. We have found this to be an especially efficient approach for constructing an information base suitable for multiresource site assessment.

## CONCLUSION

This paper has provided a rigorous terminology for analyzing the capability of forest lands to produce a variety of goods and services. It has also suggested an approach for measuring resources production as a function of ecological change induced by forest management. These advances in terminology and measurement are expected to result in greater emphasis on the significance of ecosystem structure and processes. Correspondingly, emphasis on the need for resource inventories is expected to diminish. Assessment of multiresource site quality will very likely lead to the conclusion that there are related site requirements for a large number of resources and that these requirements can be defined in terms of the structural and functional properties of forest ecosystems. Let me suggest some possible forms that these requirements may take.

We hypothesize that the following two general properties of forest ecosystems will provide sets of attributes required by a wide variety of resources (and anticipate that additional properties will be identified):

•Diversity in the structure and composition of forests
•Capability of forests to resist disturbances and to restore themselves following disturbance.

Diversity in both structure and species composition is related to smaller harvest units and a spatial distribution of unit ages that increases ecological edges and interrupts regularized patterns over large areas. Studies have shown how such diversity provides habitat conditions suitable for a wide variety of animal species. It is also related to the requirements of recreational and scenic resources.

The resiliency of forest ecosystems is important for assuring appropriate temporal distribution of resources. Forest ecosystems that require decades to recover from disturbances will be less likely to provide attributes associated with advanced successional stages, and a large share of forests in a region subject to frequent disturbances may produce only a few such benefits for very long periods of time.

Some may be intrigued by the close resemblance of these requirements to the conservative forest management traditions found in Germany (Plochmann 1981) and other European countries. Such convergence should not be taken as evidence that there is a "right" way to manage forests. Rather, it should indicate that the ecological possibilities for multiresource production are limited to a narrower set of conditions than we might have otherwise assumed.

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# Concepts of Special Significance in Forest Pest Management

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**Abstract**. Integrated Pest Management (IPM) is defined as the maintenance of destructive agents, including insects and diseases, at tolerable levels by the planned use of various techniques that are ecologically sound, economically efficient, and socially acceptable. A general conceptual model of a forest pest management system was presented. The basic components include: (1) pest population dynamics, (2) forest stand dynamics, (3) treatment techniques, (4) impact on resource values, (5) benefit-cost analysis, (6) monitoring of pests and forest stands, and (7) transferring of pest management information/knowledge to the user community. Fourteen concepts of special significance in forest pest management were briefly examined. Each concept was defined and examples given when appropriate.

## INTRODUCTION

The ecological, economic, and social values of the forests have increased considerably during recent years. We must be able to manage perturbations caused by insects and diseases as it becomes necessary to more efficiently utilize our forest resources. The philosophy, concepts, and techniques used in forestry and agriculture today to handle destructive insects and diseases is referred to as IPM. IPM is defined as the maintenance of destructive agents, including insects and diseases, at tolerable levels by the planned use of various techniques that are ecologically sound, economically efficient, and socially acceptable. Additional information on the development, concepts, and evolution of forest insect pest management is provided by: Stark and Gittin 1973, NAS 1975, Apple and Smith 1976, Waters and Cowling 1976, Stark 1977, Waters and Stark 1980, Coulson 1981, Coulson and Witter 1984, and Berryman 1986.

Foresters and forest entomologists have recognized certain key relationships between pests and forest resource management for many years (Knight and Heikkenen 1980). Waters (1978) mentions three key issues: (1) forest insects are integral components of forest ecosystems, (2) activities of insects and diseases can have major effects on forest stand growth and productivity, and (3) insects and diseases can be disruptive to forest management objectives and schedules. The key issues that IPM addresses are not new, but much of the basic research that has greatly increased our understanding of IPM was conducted from 1972 to 1985. Therefore, the implementation of IPM systems at the forest level is just beginning to occur.

## COMPONENTS OF AN IPM PROGRAM

The interdisciplinary and multidisciplinary research and application programs on major forest insect pest problems were primarily responsible for developing the major concepts of IPM in forestry. These key "big bug" projects were in operation during the 1970s and/or early 1980s, and involved the following pests: (1) gypsy moth, *Lymantria dispar* (Linnaeus), (2) bark beetles of the genus *Dendroctonus* and *Ips*, (3) Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), and (4) spruce budworms, *Choristoneura fumiferana* (Clemens) and *Choristoneura occidentalis* (Freeman). Certain unifying principles and concepts emerged, even though different insects and forest ecosystems were studied.

The general conceptual model of a forest pest management system that evolved is presented in Fig. 1. The basic components of an IPM program include: (1) pest population dynamics, (2) forest stand dynamics, (3) treatment techniques, (4) impact on resource values, (5) benefit-cost analysis, (6) monitoring of pests and stands, and (7) transferring of pest management information/ knowledge to the user.

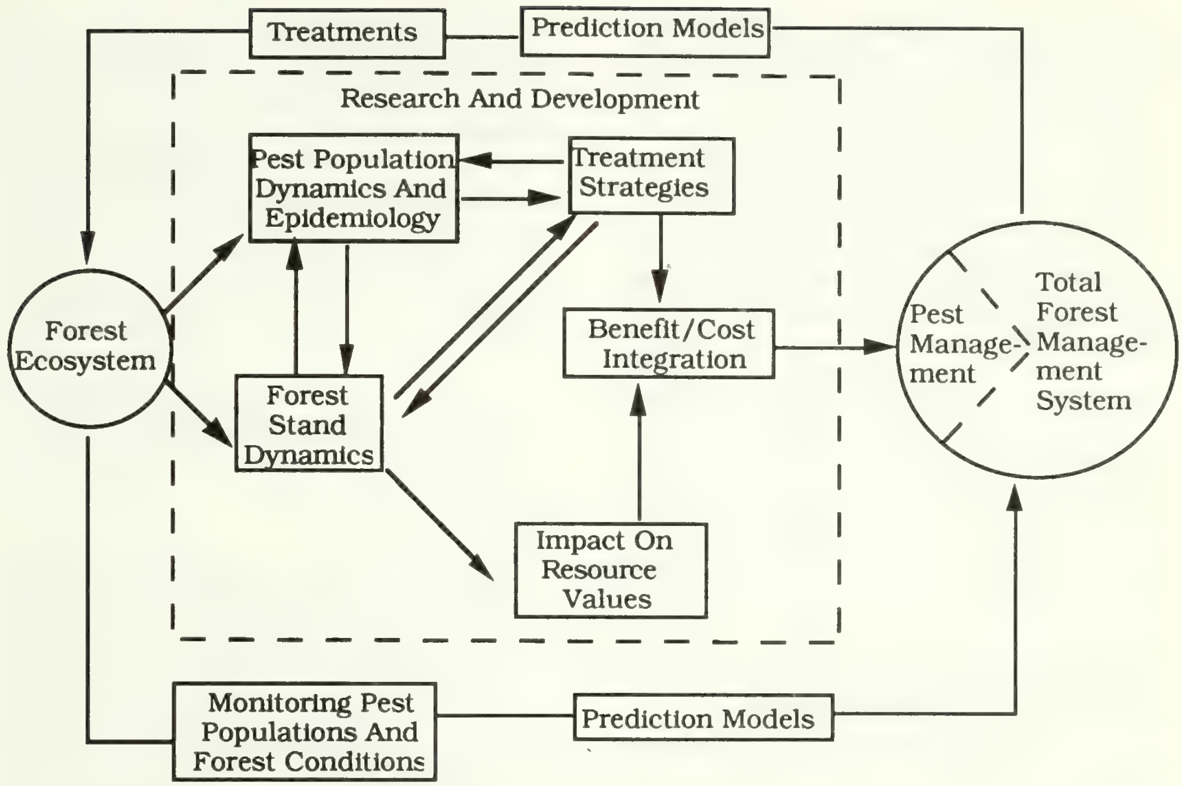


Figure 1. General conceptual model of a forest management system (From Waters and Cowling 1976).

**CONCEPTS**

The remainder of the paper focuses on fourteen concepts that I feel are of special significance in forest pest management. The specific examples used to back up the concepts come from the four "big bug" projects or from other pest insects of northern ecosystems, since most attendees at this symposium work in northern ecosystems. Additional information on these concepts are presented in Coulson and Witter (1984).

Concept I. Extent of IPM use in forestry depends on the forestry situation involved

Coulson and Witter (1984) described four forestry situations where forest insects are considered pests: (1) forest ecosystems, (2) specialized forest settings, (3) urban forests, and (4) manufactured wood products and structures. The principles of IPM in forestry were developed at the ecosystem level of organization. The IPM programs available today in forestry are used on extensively and intensively managed forest ecosystems. Examples of currently available and/or useful IPM programs are: (1) Douglas-fir tussock moth (Brookes et al. 1978), (2) gypsy moth (Doane and McManus 1981), (3) Saratoga spittlebug (Heyd and Wilson 1981, Coulson and Witter, pp. 437-438, 1984), (4) spruce budworm (Montgomery et al. 1984, Simmons and Montgomery 1985), (5) southern pine beetle (Thatcher et al. 1980), and (6) western spruce budworm (Brookes et al. 1987a,b,c).

Specialized forestry settings include forest nurseries, seed orchards, Christmas tree plantations, wind breaks, arboretums, and research plots. The components of an IPM program apply to specialized forest settings, as well as forest ecosystems. IPM practices on specialized forest settings are more like the practices used in traditional agriculture than those used on forest ecosystems. The major difference between IPM on specialized forest settings and forest

ecosystems is the heavy use of pesticides in specialized forest settings. Cameron (1981) presents an IPM program for southern pine seed orchards.

Pests in the urban forests are normally controlled with insecticides or ignored. Few IPM programs have been developed for urban forests. Montgomery et al. (1988) developed an IPM program for gypsy moth in Michigan's cities and suburbs.

Managing of pests attacking manufactured wood products and structures are usually done by the structural pest control industry. Their approach relies primarily on preventive wood treatment, pesticides, and sanitation; conceptually, it differs significantly from the IPM concept.

Concept II. There is a forest resource that needs protection from pests.

"Pests" is an anthropocentric definition given to forest insects and other organisms when they adversely affect the ecological, economic, and social values that we associate with forest and urban trees. We assume that this forest resource is valuable or there is no justification in protecting the resource from the pest. Examples of forest resources that may need protection from pests are: wood fiber, logs, aesthetic value of forests, state park campgrounds, water quantity and quality, wildlife cover, and stream habitat.

Concept III. Actual importance of a pest species is determined by evaluating the effects on values associated with a resource.

A forest pest can adversely or beneficially affect the following values in a forest: timber; water quantity and quality; fish and wildlife habitat and/or numbers; and recreational activities such as camping, hiking, fishing, boating, hunting, and observing nature. Huff et al. (1984) provides detailed information on the effects of the spruce budworm on spruce-fir forests in the Lakes States using a static economic model which established the nature of the Lake States spruce-fir market and a comparative economic model which examined changes brought about by spruce budworm outbreaks. Brookes et al. (1987a,b,c), Witter et al. (1984), Thatcher et al. (1980), and Brookes et al. (1978) present detailed information on evaluating the effects of western spruce budworm, spruce budworm, southern pine beetle, Douglas-fir tussock moth, respectively, and on various kinds of values associated with the forest resource.

Concept IV. The amount of damage associated with a particular pest is often related to the availability of a preferred plant module(s).

In describing plant-animal interactions, it is useful to employ the concept of a tree as a modular organism (Harper 1977, 1981). A module is defined as a repeated unit of a multicellular structure which is arranged in a branched system. A forest tree consists of different kinds of modules: main stem, branches, foliage, reproductive structures, and roots (Fig. 2).

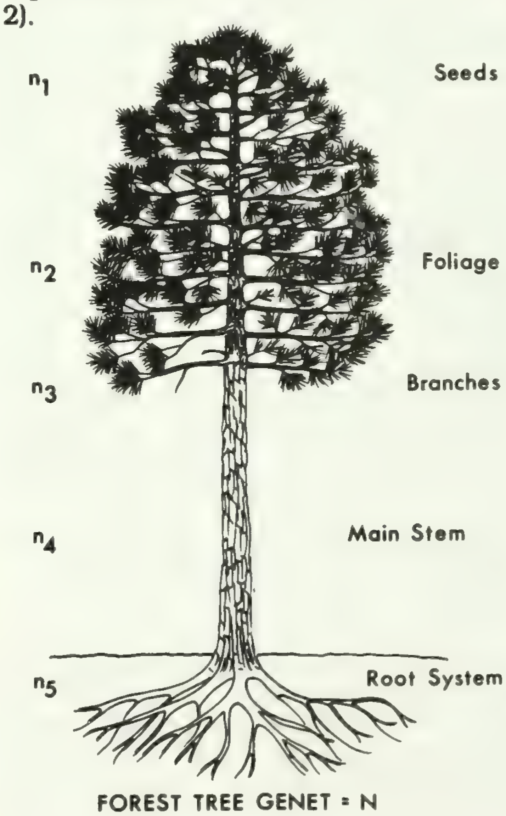


Figure 2. Diagram of a forest tree genet (N) composed of five types of structural modules ($n_1$-$n_5$).

The amount of a particular module present within a tree or stand varies considerably through space and time. For example, Witter and Waisanen (1978) showed a very significant relationship between the mean proportion of buds infested with tortricid caterpillars and the mean flushing date of aspen clones. In other words, the earlier flushing clones had a much higher proportion of buds infested than the later flushing clones.

Concept V. Mathematical models of forest trees provide information necessary for evaluation of impact at the stand level.

Stand prognosis models are used to predict the future growth of forest stands, including effects of outbreaks of forest insect populations. The stand-prognosis model represents our knowledge of how trees grow and how that growth is modified by pest management and silvicultural activities (Fig. 3). Brookes et al. (1978) and Wykoff et al. (1982) provide additional information on the use of stand prognosis models.

Concept VI. Most insects in the forests are either directly or indirectly beneficial or neutral in their relationship to humans.

It is erroneous to regard all insects as pests. Estimates of the number of insect species that occasionally cause damage in the United States vary from about 750 to 1500 species depending on the evaluation criteria used. Less than 1% of all the described species in North America are major insect pests. The majority of insects are either directly or indirectly beneficial or neutral in their relationship to human beings. Insects pollinate plants, provide food for other animals and products for human consumption, serve as natural control agents of other pests, enrich the soil, and contribute to the educational and aesthetic experience of human beings.

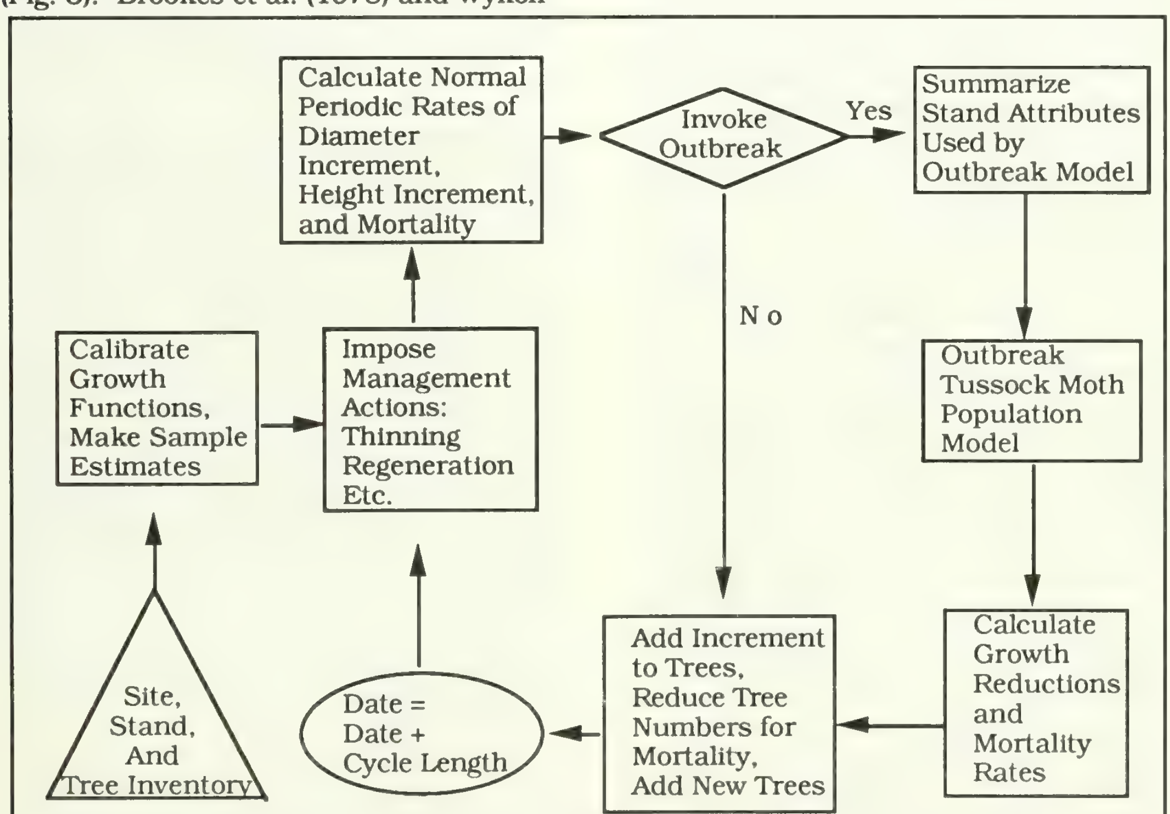


Figure 3. Stand prognosis model for Douglas-fir tussock moth (modified from Brookes et al. 1978).

Concept VII. Understanding the population dynamics of pest insects is essential so that we can describe how a system will operate under different conditions.

It is necessary to consider a population as a system of interacting components to understand how and why insect distribution and abundance change through space and time. The basic components of a population system are: (1) environmental properties, (2) individual properties, (3) population processes, and (4) population state variables (Fig. 4). Coulson and Witter (1984), Berryman (1981,1982), and Clark et al. (1967) provide additional information on the components of the population system and factors responsible for changes in distribution and abundance of populations.

Concept VIII. Forest insect outbreaks can be classified into six types.

Berryman (1986) identified six types of insect outbreaks which were divided into two broad classes. The broad classes are eruptive outbreaks, characterized by their self-perpetuating spreading nature, and gradient outbreaks, characterized by arising and subsiding in place in response to external environmental conditions. The outbreak subclasses reflects the tendency for an insect population to cycle with regular periodicity, to decline rapidly after reaching outbreak numbers, or to persist in place for several insect generations. Berryman (1986) describes the six types of outbreaks as: (1) Sustained eruption – persist at high densities for several to many years at any one location and host plants only die after many years of attack, if at all, (2) Cyclical eruption – occurs at regular intervals (e.g., 8 to 11 years apart), and never causes severe or widespread mortality of host plants, (3) Pulse eruption – occurs at irregular intervals and often causes widespread mortality to host plants, or is quickly terminated by natural enemies, (4) Cyclical gradient – occurs at regular intervals (e.g., 8 to 11 years apart), rarely causes extensive mortality to host plants, often associated with particular site and stand conditions, and is usually terminated by natural enemies or by host-defensive responses, (5) Sustained gradient – occurs more or less continuously on particular sites and stands, and (6) Pulse gradient – occurs at irregular intervals, following major environmental disturbances or outbreaks of other organisms, and subsides soon after environmental conditions return to normal. Land managers will be better able to create conditions where insect populations are maintained at tolerable levels when the managers understand the basic insect outbreak patterns and the feedback processes that give rise to the various outbreak patterns.

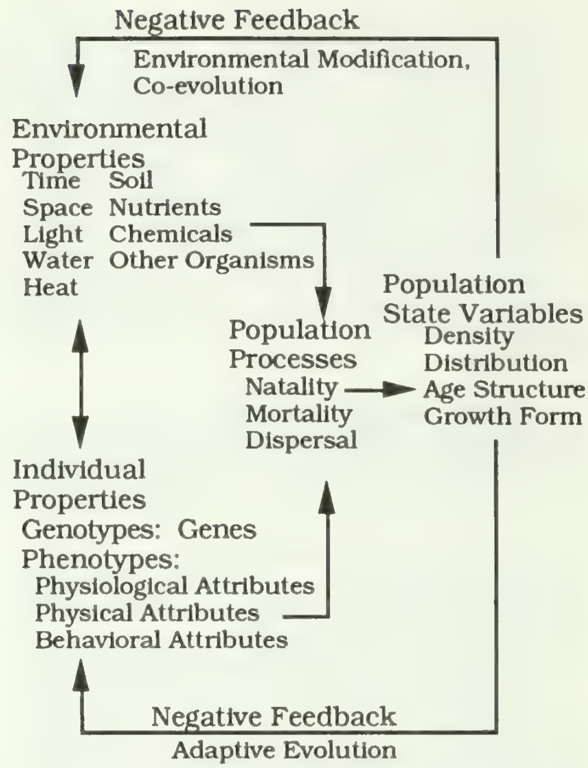


Figure 4. Basic components of a population system (Modified from Berryman 1981).

Concept IX. Monitoring pest populations and forest stands is a necessary component of IPM.

Normally, monitoring of forest stand conditions and pest population numbers are undertaken as separate surveys. They are represented at the periphery of Fig. 1 linking activities taking place in the forest ecosystem to predictive models

and finally to forest resource management. Monitoring the conditions of forest stands are often done using aircraft, remote sensing techniques, video cameras, GIS, and computers. Monitoring insect populations varies considerably depending on the specific forest insect. See Sanders et al. (1985), Coulson and Witter (1984), Doane and McManus (1981), Thatcher et al. (1980), and Brookes et al. (1978) for specific techniques used to monitor various pest populations.

Concept X. The land manager uses cost-benefit analysis as a tool to make judgments on what actions to take.

If the land manager believes that there is a problem from an insect outbreak, judgments must be made on what action to take (treatment or no treatment). The land manager then evaluates all possible treatments and the impact that the treatment will have on resource values. Cost-benefit analysis is the procedure used to make judgments (Sassone and Schaffer 1978). One chooses the action that gives the greatest positive difference between costs and benefits.

Concept XI. A number of techniques often are available to reduce pest populations.

Information on pest population dynamics, stand dynamics, impacts on resources values, and costs of application are used to determine if a treatment(s) is needed and what technique(s) to use. Techniques used to suppress populations are: (1) chemicals, including insecticides, behavioral chemicals, and hormones, (2) biological control using natural enemies such as insect parasites, insect predators, avian predators, and pathogens such as bacteria, viruses, or fungi, and (3) mechanical control such as trapping insects, destroying habitat, modifying habitat, or collecting insects from the host. Techniques used to prevent insect outbreaks include silvicultural methods and regulatory practices such as quarantines or containment and suppression programs designed to prevent spread of pests into new areas. Additional information on techniques used to reduce forest pest populations is provided by Knight and Heikkenen (1980), Coulson and Witter (1984), and Berryman (1986).

Concept XII. IPM programs can be simple or complex.

IPM refers to the philosophy, concepts, and techniques that are used to handle destructive forest pests. Therefore, a successful program may be fairly simple or complex. The general conceptual model (Fig. 1) was developed for large complex insect/stand interactions and implies that each component is a complex subsystem, and ideally consists of detailed information which is abstracted in the form of a predictive mathematical model (Coulson and Witter 1984).

A relatively simple IPM plan is being used for reducing Saratoga spittlebug damage on red pine in Michigan (Fig. 5, Heyd and Wilson 1981). A proposed planting site or an established plantation is risk-rated for Saratoga spittlebug damage. Saratoga spittlebug causes economic damage only when suitable alternate hosts are present. Heavy infestation of the Saratoga spittlebug is normally correlated with density of sweet fern. Risk-rating of proposed planting sites or young plantations under 5 m tall is conducted during the spring or summer when alternate hosts are present. The forester or pest management specialist determines the percentage of ground cover occupied by sweet fern at chosen intervals within the site. A risk-rating triangle is used to determine whether the area is of low, moderate, or high risk. Data for the entire stand are sketched onto a map. With this survey information, the land manager can apply preventive, silvicultural, or chemical techniques. The prevention technique involves restricting red pine to only non-risk or low-risk areas. Silvicultural techniques that reduce the number of alternate host plants are deep plowing, shallow plowing, or chemical herbicides. Registered insecticides may be used effectively against the adult spittlebug if a spittlebug problem develops in an established plantation. The land

manager uses a net present value analysis for each management strategy before making the final decision on technique(s) applied to a particular site or plantation.

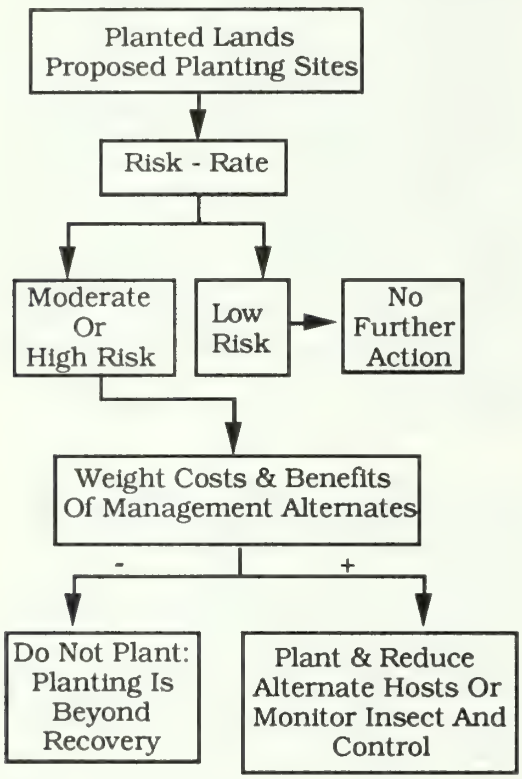


Figure 5. Flowchart of steps in determining management strategies for red pine based on potential susceptibility to damage by Saratoga spittlebug (After Heyd and Wilson 1981).

<u>Concept XIII. Pest management is a component of forest resource management</u>.

This is a very important concept that entomologists and pathologists often forget or downplay. A pest management program for an organization (ie., national forest, state forest) should not be a stand-alone program, but must be incorporated into the long-term plan for the organization. Specifically, insects and diseases need to be considered when the forester enters the compartment every 10 years so that it becomes primarily a preventive philosophy for control instead of a suppressive philosophy for control.

<u>Concept XIV. It is essential that the forest pest management specialist: (a) has a plan for transferring technology to the user community and lay public, and (b) uses the plan to inform and educate the user community and lay public about the pest problem</u>.

Witter et al. (1982) and Montgomery et al. (1984) document a very successful technology transfer program that was developed and used from 1981 to 1985 to provide land managers in the Lake States with pest management information on the spruce budworm. It is important to review this technology transfer program, because, unlike agriculture, forestry has few examples of well-organized or time-tested technology transfer programs. Montgomery et al. (1984) offers the following advice on developing a technology transfer program: (1) Understand the various institutional forces and constraints within which you operate, (2) Focus your attention on the problem and identify your target audience, (3) Involve people relevant to the issue and establish an advisory committee to oversee project activities, (4) Review past and current research activities that relate to the problem, (5) Review other technology transfer efforts in forestry and natural resources; incorporate their strong points into your plan, when appropriate, (6) Develop a short, simple,and flexible plan, (7) Clearly state your objectives, (8) Get to know your audience, and understand their perceptions and beliefs regarding the problem, (9) Learn what factors help and hinder the technology transfer and innovation decision process, (10) Base your choice of what information to disseminate on needs assessment surveys and the expertise of your staff; (11) Base your choice of media on the type and size of audience and the message being disseminated, (12) Consider using "information movers" (e.g., cooperative forestry extension agents) as your primary audience or divide your audience into smaller groups if your target audience is large, (13) evaluate your process, products, and impact of program, (14) Realize that ideas, objects, and practices will be adopted and implemented at different

rates, and (15) Attempt to institutionalize your program.

Methods commonly used to inform and educate the user community and lay public about pest management problems include newspaper articles, magazines, manuals, handbooks, leaflets, workshops, radio and TV spots, computer software packages, talk shows, meetings, films, and personal contacts.

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# STRATEGIES FOR SETTING RESEARCH PRIORITIES IN DISCOVERING NEW KNOWLEDGE ABOUT FORESTS

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**Abstract**. Strategies for setting research priorities in discovering new knowledge about forests must be developed with a systems perspective of forestry research. Research priorities should reflect the multiple value systems of the many actors who play important roles in making decisions within forestry research systems. In developing research priorities it is important to recognize and, if possible, reconcile the different value systems of those who fund research, manage research, do research, disseminate research, and use research results. In modern, technology-based societies, choices about science inevitably involve more than the professional concerns of scientists.

## INTRODUCTION

Forty years ago Vannevar Bush (1945) aptly characterized science as "The Endless Frontier". Today scientific research still seems to raise more questions than it answers, and scientific frontiers continue to expand with no end in sight. In any field of science many questions remain unanswered that could be the subject for research. Some of these questions may be critical to solving important scientific or social problems. We don't have enough resources, people, funds, facilities, and time, to answer all scientific questions that arise in the course of research. In forestry research, as in other fields of science, we are forced to make choices of what research projects or programs to work on. We must set priorities on what, how, when, and where to study. In setting research priorities the tough job is to select important problems that are do-able within a reasonable time and within an allowable budget.

In the limited time we have today I want to explore with you some of the factors that should be considered in developing strategies for setting research priorities in discovering new knowledge about forests. This will be a brief review that can only hint at the complexity of the subject.

## FACTORS AFFECTING THE SETTING OF RESEARCH PRIORITIES

In modern technology-based societies, choices about science inevitably involve more than the professional concerns of scientists. People in modern societies are deeply affected by direct and second-order consequences of technological innovations that arise from the growth of scientific knowledge produced by research. Scientific research has become an integral part of the economic and social structure of our society. In a political context it is important to recognize and address the concerns and value systems of the different power groups involved in research decisions. I shall argue that in deciding what research to do in forestry, in developing strategies for setting research priorities, it is important to go beyond the immediate professional concerns of scientists and consider the concerns of others in society who take part in and are affected by forestry research decisions.

Much of the philosophy of science literature concentrates on developing logical-scientific methodologies and criteria that underly choices of topics for scientific research and research methodologies (for example, Platt 1964 and Bunge 1967). This is critically important in improving the scientific effectiveness of research. Yet, I would argue that this addresses only part of the problem of setting research priorities.

We recognize that there is a strong irrational/illogical element in scientific research and discovery (Brown 1977). The history of science recounts many instances of major scientific discoveries being made through blinding flashes of intuition when least expected. Strategies for setting research priorities should allow for nonrational elements in the process of scientific research. We know that scientific discovery is not a deterministic activity. Rather, it contains a large measure of uncertainty. Forestry research is not a tightly structured, closed, deterministic system that lends itself to quantification and prediction. Rather, it is a loosely structured, open, evolutionary, uncertain system that is difficult to quantify and defies precise prediction. Because science is evolutionary it is difficult to anticipate the future development of a given field of science, the acceptance of new scientific discoveries by future scientific communities, and potential impacts of such discoveries on science and society. This greatly complicates the planning and evaluation of future research projects and programs. Strategies for setting research priorities must reflect this basic uncertainty.

We are aware that science is a social activity that takes place within a community of scientific peers (Mulkay 1977). Knowledge does not become a part of science until it is shared publicly with others in the scientific community. The accumulated acknowledged body of scientific knowledge helps to determine research priorities within a scientific field.

Science is strongly dependent on the rest of society for the financial support of research and for the education and training of future scientists, among other things. Science also strongly influences technology and thus affects the lives of people throughout society in many ways, directly and indirectly (Ziman 1976). The voices of interest groups in society may play an important role in shaping research priorities.

All of these factors, and others, should be considered as part of a strategy for setting research priorities in forestry.

## A SYSTEMS VIEW OF FORESTRY RESEARCH

Strategies for setting research priorities in discovering new knowledge about forests must be developed with a systems perspective of forestry research. The forestry research system invovlves more than the actual doing of research, more than the interests of scientists and their value systems regarding scientific research. Forestry research is part of society and has a broad influence throughout society. Many different groups of people besides scientists are part of and have a direct or indirect interest in forestry research. These different groups influence what, where, when, and how research is done. They frequently have differing value systems that reflect their own interests, education, training, and background. In developing research priorities it is important to recognize and, if possible, reconcile the different value systems of those who fund research, manage research, do research, disseminate research, and use research results, as well as all those throughout society who ultimately are affected by the choice of new technologies. Criteria for establishing forestry research priorities should reflect these multiple value systems.

In looking at the forestry research system one can identify five major groups of people in society who are involved, directly or indirectly, in forestry research:

- Those who fund research;
- Those who do research;
- Those who disseminate research findings;
- Those who use research results;
- Those who are affected by the use of research results.

Each of these groups has an interest in the development of forestry research priorities.

**Funders of Research** — Federal and State legislative bodies, government agencies, and other public and private sources who fund research must judge and select from among a host of competing programs, both research and non-research. The decision makers and their staff have

organizational and personal values that affect their choices. These must be considered in developing research priorities.

**Doers of Research** — Much of forestry research is carried out by government research organizations and by university forestry schools and agricultural experiment stations. Organizational administrators have to justify research programs, funding levels, and facilities to those who fund research and to others. The priorities they place on research projects and programs reflect their concerns. Research managers must organize the people, facilities, and funds available to them to accomplish research goals. The priorities they place on forestry research reflect their responsibilities. Research scientists set research priorities based on their own concerns. They must use the skills and resources at their disposal to conduct research successfully and produce results that will meet with the critical approval of their peers. In establishing research priorities the doers of research must somehow reconcile the differing interests and value systems of research administrators, managers, and scientists.

**Disseminators of Research Findings** — Research findings must be disseminated to their intended users if they are to be of value to science or to society. Many are involved in this dissemination process: individual researchers, research organizations, extension personnel, teachers, professional journals, professional societies, libraries, book publishers, other media, and perhaps most important, other users of such research results. All of these help shape the priorities placed on research through their role as gatekeepers in the transmission of research results to potential users.

**Users of Research Findings** — Research scientists, as scientific peers reviewing project proposals, study plans, and other documents relating to proposed research in forestry, greatly influence research priorities. Through their critical comments about completed, current, and proposed research they can affect the selection of research problems and methodologies. Field foresters and others who expect to apply research results can influence priorities placed on proposed research.

**The Public Affected By Research** — Individuals, groups, and organizations outside of the research organizations may be impacted by a proposed line of research. They may use their political influence or use other means to influence the choice of research topic, the research methodology, or the level of funding provided for a given type of research.

In the research process there are several actions that must be undertaken. Researchers must:

- Decide what research to do. This is the strategic phase of research.
- Decide how to do the research. This is the tactical phase of research.
- Do the research. This is the operations phase of research.
- Communicate research results to scientist peers and other potential users. This is the diffusion phase of research.
- Monitor use of results and take action to correct defficiencies detected in the research process. This is the feedback phase of research.

Each of these research activities requires the involvement of different groups of people who are part of the research system. Each activity requires different information about the system. In setting research priorities each activity should be considered and evaluated for each proposed research project or program.

## STRATEGIES FOR SETTING RESEARCH PRIORITIES

In developing strategies for setting research priorities in forestry it is important to recognize and incorporate the value systems of the different groups of people involved in forestry research. The people involved in a proposed research project or program depend in part on the type of research being done. To determine the type of people who might be involved in research, it is helpful to distinguish between basic and applied research, although this is not

always easy to do. These two types of research affect science and society in different ways and involve different groups of people.

It is helpful to think of basic and applied research as two ends of a continuum, rather than as two sharply divided classes of research. At one end of the spectrum lies basic research. For this discussion I will define basic research as research aimed at producing knowledge about or an understanding of some aspect of the natural or human world, to be used by other research scientists as an input to further research. Thus, the primary users of results from basic research are other scientists, and perhaps some scholars and educators. The results would be published in scholarly scientific journals, to be read by peer scientists. In other words, basic research is done to provide input to more research.

In contrast, at the other end of the spectrum is applied research. Here the aim is to produce knowledge, information, or new technologies that can be used to change the way things are done in the world around us. The intended users of results from applied research would be those people outside of the research establishment who do things. In forestry this might include land managers, forest product harvesters, forest products industries, and other groups of people who use forests and their related goods and services.

Much research may fall somewhere between these two extremes, producing knowledge, information, and new technologies that may in part be used as input to future research and in part as input to change the way things are done in the world around us.

If proposed research is primarily basic, then the important values to be considered are the potential contributions that this research might make to science. Such contributions to science are difficult to quantify and involve peer judgement to a large degree.

If the proposed research is mainly applied, and intended to change the way things are done in society, then the important values to be considered are the anticipated kinds and intensities of changes, and the extent of their social, economic, and environmental impacts.

Different strategies are needed to determine research priorities in each of these two extreme cases.

It is important to recognize that there is no one overall system for setting research priorities in forestry. Each organization, each of the different groups of people involved in the forestry research process, has its own strategy for determining priorities. The outcome is likely to be a set of conflicting research priorities that cannot be resolved analytically, but only through some political bargaining process among various interest groups.

## CRITERIA FOR SETTING RESEARCH PRIORITIES

If we want to set priorities on several potential research problems or projects, then we must evaluate these research alternatives according to some criteria. Many criteria have been suggested for evaluating research projects. We have time only to mention briefly two sets of criteria that would be useful in setting research priorities.

The National Science Foundation[1] has used four criteria to evaluate research proposals:

1. Research performance competence —
   Are the investigators capable?
   Is the approach technically sound?
   Are there adequate institutional resources available?
2. Intrinsic merit of the research —
   Is it likely that the research will lead to new discoveries or fundamental advances within its field of science or engineering, or have substantial impact on progress in that field or in other scientific and engineering fields?
3. Utility or relevance of the research —
   Is it likely that the research can contribute to the achievement of a

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[1] From APPENDIX B (Attached to NSB - 81-384). Approved by NSB, 8/21/81.

goal that is extrinsic to or in addition to the goals of the research field itself?
Is it likely to serve as the basis for new or improved technology, or assist in solving societal problems?

4. Effect of the research on the infrastructure of science and engineering —
Does this research have the potential to improve the understanding, quality, distribution, or effectiveness of the Nation's scientific and engineering research, education, and manpower base?

In addition, I suggest that we should ask of each alternative:

Does this research problem fit with the unit's research mission?
Will its solution help to achieve the unit's goals?
Can the choice be justified to those who will fund the research?

Can it be done?
Are the skills and resources available to do the research within a reasonable time?
Is there a reasonable chance of success?
If not, are the potential gains if successful large enough to offset the low probability of success?

Would the results be used?
Could the results be used by the people for whom they are intended?
By others?
Are they likely to be used?
Is the problem important?
Would the results be widely used?
If the results were widely used, what differences would it make?
What would be the impacts of their use? How much, where and when?
What would be affected, and to what extent?
Who would be affected?

## CONCLUSION

I think we all could agree that with limited resources available for research it is important to develop strategies for setting priorities on potential topics for research. I have suggested that such strategies must:

- Insure that basic logical-scientific methodologies and criteria are met.
- Allow for the nonrational elements and uncertainties inherent in research.
- Recognize the social dimensions to scientific research, the interactions among scientific peers and the interrelations of science and society.
- Incorporate a systems perspective of research and address the different value systems of the diverse groups that play a key role in the forestry research system, including those who:
  Fund research;
  Do research;
  Disseminate research findings;
  Use research results; and
  Are affected by the use of research results.
- Recognize that separate strategies are needed for basic and applied research. Priorities for basic research are set primarily by those scientists who do the research and use the results. Priorities for applied research must consider potential impacts on society.

Many criteria have been suggested for determining research priorities. One of the most simple but profound sets of criteria I have encountered was given by Dr. Charles Muscoplat, Molecular Genetics Inc., Minneapolis, Minnesota, at a meeting on research policy in March 1982. He suggested three criteria that any research proposal must meet, at a minimum, to be considered a viable research alternative by his company:

- **Is it doable?** Not just, Is it a problem? But, Is it something that we can do with our skills and resources within a reasonable time and be pretty sure of success?
- **Is it usable?** Could it be and is it likely to be used by the people you intend it for?
- **Is it important?** Will it be widely enough used and make enough difference to have an important impact?

Any strategy for setting research priorities that answers those three questions

— Is it doable? Will it be used? Is it important? — will go a long way towards developing more effective research programs in forestry.

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# INTERGRATING SOCIAL SCIENCES INTO FOREST RESOURCE RESEARCH

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**Abstract**. Forestry and the value of forest resources are inexplicitly intertwined with the human habitat and social value systems. Traditional forestry studies and forest management have generally concentrated on narrow academic disciplines related to the growing and harvesting of trees. This paper discusses the need to broaden the base of scientific disciplines for forestry to include social sciences. The possibility of integrated systems analysis studies for forestry is also examined.

## INTRODUCTION

The need for integrating multiple resource inventories and inter-disciplinary research on forests is often stated. For example, the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976 explicitly direct the U.S. Forest Service to assess the total renewable resource situation on all forest lands. The National Environmental Policy Act of 1969 requires Federal agencies to "utilize a systematic interdisciplinary approach which will insure the integrated use of natural and social sciences ... ."

Current forest resource research often follows narrow disciplinary lines even though research objectives are guided by broader economic and social needs which are better assessed by methods of social sciences. This paper explores the possibilities of greater use of social sciences as an integral part of forest resource study and management.

## THE IMPORTANCE OF SOCIAL SCIENCES

The purpose of science is to understand how things work. The purpose of social science is to help us understand how society works. Societies involve interactions (functions or behaviors) and patterns of relationships (structures) of two or more people. In the broadest sense a society can consist of as few as two people or as many as all on earth, i.e. the socalled modern global village. One person cannot be a society, thus individual thought or study is the purveyance of psychology or philosophy.

Social sciences are not usually viewed as a single field. Just as the natural sciences are divided into such areas (disciplines) as physics, chemistry, biology, geology, and astronomy—to mention only the main headings—so are the social sciences also divided. We typically think of six social sciences: sociology, economics, political sciences, history, anthropology, and human geography. In addition, psychology can also be considered as a social science when it deals with groups, even though much of its study is about the individual.

Economics deals with the production and distribution of marketable goods and services and the allocation of scarce resources. Economics is used extensively in forestry management in allocation of resources and investment decisions. Political science studies government and the effects of government institutions have on how things work. Sociology deals with all of the human interactions between individuals not dealt with by economics or political sciences. These three main social sciences are independent of time and place.

Anthropology studies particular societies and how the patterns of living differ and on differences in cultural values. History gives explicit times places, and persons or groups usually with emphasis on time sequences of events. Geography gives special attention to particular places and to relation of things to space. Psychology to the extent that it relates to understanding the relationships of individuals or societal groups can also be considered a social science. In addition, combination of discipline such as eco-

nomic history, political economy, social psychology, or economic geography are recognized as separate specialty study areas (Kuhn 1975).

The need for substantive interdisciplinary analysis is outlined by Sherif and Sherif (1969) who write:

> The core problem of interdisciplinary relationship for a particular science is to determine what findings and what concepts it has to borrow and in what matters it has to be in transaction with other disciplines in order to stand firmly on its own feet, with all of supporting evidence that it needs to insure the validity of its formulations. It will not gain this support by standing like an ostrich with its head ground into a fixed hole through the sheer force of orthodoxy. On the contrary, assessment of what it needs from others and with whom it needs to transact will provide ingredients for weaving its own fabric. It will provide a balanced view of its bearings relative to other disciplines.
>
> After all, no scientific discipline is an island unto itself. It cannot develop firmly in isolation from others. Deliberate assessment by one discipline of what is needed from other disciplines and who it needs to transact with will provide a center of gravity for its own development that is conducive to probing its problems to any degree of intensiveness desired. In fact, intensive study of its own domain will gain both in depth and scope. Insulated from related disciplines and lacking firm bearings relative to them, intensive study within a discipline sooner or later starts to produce floundering expeditions into territories already explored by other disciplines, with the resulting exhibitions of ignorance that have been displayed in the past by psychologists who sociologized their own brands of human motivation or perceptions. It should be clear that what is being advocated as the core problem of interdisciplinary relationship for a particular science is a cry from hastily conceived notions of interdisciplinary study as a flashy veneer of the finishing school which aimed to turn out young ladies who could converse gracefully on diverse topics in a drawing room.

It has been remarked that many of the difficulties that beset the world today can be explained by the fact that progress in the social sciences has lagged far behind that of the physical and biological sciences. Moreover, the continued explosion of knowledge in biotechnology, computers, material science, and other natural science and engineering areas will have profound implications for forest research and human society as a whole. For social and technological factors interact and technological development is often determined by social logic rather then technological logic (Bijker et al. 1987). On the one hand the potential for improved biological and physical production is great, while on the other lack of social and economic control threatens the the very environment of the planet. Problems of maintaining the environment, providing sustainable economic development, managing disruptive social change, and the equitable distribution of resources are of major concern in many parts of the world today. These concerns are expressed by Arno Rosemarin, editor of AMBIO[1]

> The term 'forest' stems from the Latin *foris* meaning outside or outdoors. That forests often determine the habitat limits to man's terrestrial existence is, unfortunately, not implied from the term. Today, our knowledge about forests and terrestrial ecology is being seriously challenged by observations of long-range transportation of pollutants, forest decline, climate change, global ozone shifts, etc. The message is also clear that the more "conventional" resource management-type problems relating to forest exploitation, silviculture and agroforestry, require complicated solutions which challenge even the best forest managers.

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[1] From an editorial in AMBIO A Journal of the Human Environment, Vol XVI No. 2-3 published by the Royal Swedish Academy of Sciences.

**FORESTRY AND SOCIAL SCIENCES**

Forestry needs to broaden its base of scientific disciplines to maintain its position of leadership in forest resource policymaking (Clausen 1977). Some forest economists led by Professor William Duerr, have attempted to expand the use of social sciences in forestry. However, most research is limited to studies of economic efficiency and resource allocation. For example, see the index of social sciences in forestry which was compiled for many years under his influence and is now compiled at the University of Minnesota (Albrecht 1987). Traditionally American forestry has based its policymaking foundations on biological models from European traditions combined with eclectic models of timber harvest and utilization. As Peter Glück (1987), an Austrian forestry professor observes:

> The History of forest management is maybe characterized as a history of reckless handling of forests, resultant catastrophes, and response in the form of the establishment of doctrines for achieving harmony. These doctrines are 'timber primacy,' 'sustained yield,' 'long term,' and 'absolute standard'. Originally from Europe, they invaded North America and influenced forest activities all over the world. The four doctrines form the basic framework of academic forest science curricula and have legal status in many countries.

This has led to a concentration on timber management and harvesting as its major areas of concern (Clary 1986). A recent survey by Hendee and Roggenbuck (1984) indicated that of 542 wilderness related courses, only 13.2% were offered by Forestry Departments. Overall, 27.2% were in Resource Management Schools, 17.0% in Biology related schools, and 56% in Educations or Social Science Schools. Implications of involvement of non-resource schools in wilderness appreciation and is additional evidence that the wilderness concept is central to the larger conservation movement. For example, see, "Wilderness and the American Mind" by Nash (1982), a historian. If foresters are not involved in the further articulation and evolution of the wilderness concept, they may similarly be bystanders to the evolution of conservation thought.

The growing concern for conservation is further evidenced by the principles of the World Wilderness Congress which is dedicated to balanced stewardship of the world's natural resources as being essential to human survival and well-being; and conviction that commercial and industrial growth must go hand-in-hand with protection of a spectrum of wild and natural places. Those principles call for balance, dialogue, tolerance, respect, and conservation for survival and human development. They relate wilderness and resource management to conservation and human concerns. The 4th Wilderness Congress planned of Fort Collins Colorado in 1987 emphasizes strengthening world conservation efforts through science, management, and citizen's efforts. According to Hughes and Hendee (1984): "The 4th World Wilderness Congress will be an opportunity for foresters to demonstrate their interest and efforts in broad aspects of conservation and balanced stewardship of natural resources."

Social and cultural attitude toward forestry, forest policy and forest practices is particularly important in determining economically and environmentally successful programs. Current concerns about loss of tropical rainforest because of unsustainable and environmentally damaging economic development projects point out the need to consider cultural and socio-economic factors beyond strict financial investment analysis. Understanding the cultural, social, and economic structure of indigenous peoples is also important for forest management. As Clawson (1975) argues:

> It seems to me there is a great need for sociological research about cultural attitudes towards forest, forestry, forest practices. We need to know much more accurately than we now know, what public attitudes are, to what extent they vary among groups according to the usual socioeconomic factors of age, education,

income, social class, and the like. More importantly, we need to know why expressed attitudes are held, and what are the trade-offs may between cultural attitude and economic gain. Perhaps the day will come when the forest sociology will be as well recognized as silviculture in the training and expertise of the forester. Until now, foresters and all the rest of us have relied too heavily upon 'common knowledge' and intuition; cultural attitudes toward forestry are as capable of enlightening research as are any biological aspect of the forest.

Most foresters prefer to deal with research in natural sciences. Here the tradition scientific method works well—problem definition, discovery, hypothesis testing, and hypothesis conformation/rejection. Most terms can easily be described in arithmetic terms, codified and modeled mathematically. Many traditional foresters would believe social sciences are un-natural sciences, at best irrelevant, at worst inimical to the study of classical forestry. Their feelings might best be summed up by W.H. Auden's little verse:

"Thou shalt not sit
with statisticians nor commit
a social science".

Management of the forest resource system requires a varying degree of knowledge from a number of different disciplines. Particularly when viewed from the prospective of international forestry, where cultural differences and political and economic expediency often dictate resource use decisions, which may not be environmental sound or desirable. Clawson (1975) has developed a conceptual framework for analysis for forest policy analysis. He categorizes five general criteria for forest resource evaluation. They are list as follows: (1) physical and biological feasibility and consequences, (2) economic efficiency, (3) economic welfare or equity, (4) social or cultural acceptability, (5) operational or administrative practicality.

It is possible to define the capacity of the biophysical environment of various area's of forestland with respect to their abilities to produce a bundle of attributes which we call resources. It is difficult enough to define the physical and biological variables and measure them, let alone define the consequences of various actions in terms of biological potential and resource output. The facts of nearly all situations may be subject to dispute—at least interpretation of the facts. As much agreement on the physical and biological facts must be obtained as possible and relevant resource use questions asked. The social scientist or policymaker must nearly always make a decision under uncertainty, and risk must be reduced wherever possible.

Economic efficiency with respect to the costs of forest investment benefits from the forest and return of investment capital are of major concern in forest management. Evaluation of non-market output from forest such as wildlife, genetic diversity, recreation, wilderness, watershed values, aesthetic value, and any other things not sold directly in markets is particularly difficult. Economic analysis can show the efficiency of producing one forest output as compared with other mixtures of outputs. Sophisticated methods of economic analysis of costs and benefits from natural resource development have been developed. They, however, are no better than the data upon which they are based. They also do not address questions of sustainable development and the impact of forestry programs on the distribution of benefits or the external environmental cost which may be incurred.

The economic benefits of forest management and forest research programs accrue to certain individuals or groups and the cost are borne by other individuals or groups. Seldom are those who benefit the same as those who pay. Often there are also some people who have additional costs or disadvantages when a particular project or management activity occurs. For example, a small landowner may be displaced when a large forest plantation project is developed. The benefits may go to the corporation or the development agency who sponsors the project. A new wilderness area or park may result in fewer

jobs for forest industry. The problem is one of economic equity and economic welfare.

Economic efficiency is not enough to develop acceptable forestry programs. Men do not seek to maximize their material well-being to the exclusion of all else. Everyone is a Economic Man up to a point, but as the economist Kenneth Boulding states – he certainly would not want his daughter to marry an Economic Man. Social, cultural, and political reality must accompany forest policy and its management programs. Burch (1977) outlined some of the factors that should be considered in studying the social aspects of forestry and formulation of national attitudes toward forest resources.

There must be the resources, the means, and the will to carry out a forest policy and its management program. This includes the technical competence, the competent administrative structure for decision-making and implementation, and finally, sufficient men, money, and machines to do the job. Political and social acceptance and economic compensation may be needed for a program that requires the cooperation of many small landowners or users.

Forest policy research needs an approach that integrates all of these criteria into a unified framework. What's more, there are additional areas such as community or societal stability and maintenance of the integrity of the environment which need to be considered. In the end of his comprehensive analysis of the social aspects of forest policy, Burch (1977) states that forest policy research could invoke all the disciplines from anthropology to zoology. Certainly, the social sciences should play a prominent role in the analysis of forestry research and decision-making.

## SOCIAL SCIENCES AND SYSTEMS ANALYSIS

In the social sciences, the attempt to emulate the ideal pattern of the natural sciences has led to unnecessary frustration (Brodbeck 1968). By being able to point to the comparative vagueness of their concepts, to the comparative inexactness of their derivations, and to the comparative unreliability of their forecasts, many social scientists rationalized their procrastination and accepted a stagnation of progress in their field that is quite incompatible with the tremendous strides toward an enriched understanding of human interactions that have actually occurred, not only in economics and psychology but to an almost equal degree in sociology and political science (Helmer, 1966).

Social sciences differ somewhat from the classical scientific model of natural sciences in that terms, logical constructs and "laws" may vary through time or between cultures. The definition of concepts may also be different. The economist, Nicholas Georgescu-Roegen (1966), makes the distinction between Aritmomorphic Concepts which have a precise arithmetic meaning and Dialectic Concepts whose meaning is subjective to various contextual meanings. There is however one area of common ground which can be used to unify the difference between various disciplines of natural and social sciences, that is, the concept of systems analysis.

Systems Analysis concepts have been used in forestry since the 1960's when they first became in vogue. Generally, however, system analysis techniques have been applied to familiar problems such as modeling forestry activities like land management or timber harvesting. For example, see the symposium of systems research conducted by the Society of American Foresters (Meadows, et. al. 1975). The broader concept of system analysis techniques has been used by other social scientist and engineers. Orcutt et al. (1961) first tried a large scale multi-disciplinary study of the microanalysis of socioeconomic systems. More recently, Krone (1980) details scientific knowledge as developed, structured, and applied to systems analysis and policy science. He diagrams the scientific method of systems analysis with an explanation of why systems analysis is art as well as science. The engineering oriented systems approach of heuristic problem-solving are

outlined by Wilson (1984). This approach provides a wide range of problem solving techniques and systems management concepts. Systems analysis provides a common ground in which foresters can relate concepts from many scientific disciplines in an integrated form for forestry research. As Gerald Weinburg (1975) writes:

> The general systems approach, then, can engender a parsimony of thought for the study of subjects. A similar economy is introduced in the study of situations, or special systems. In our experience, the general systems approach has provided a starting point for the study of a myriad of information systems, complex machines, social systems, individuals and working groups, and systems of education. Others have found the general systems approach useful in meteorology, political science, biology, sociology, psychiatry, ecology, engineering, and in fact just about any discipline you can name.

## FOCUS ON INTEGRATED SYSTEM SCIENCE FOR FORESTRY

Forestry is the the study and practice of managing forest land and associated resources and the proper role for foresters is "The creation and use of all forestry values from scenery to wood" according to Duerr et al. (1979). Forestry is further viewed as a system: a set of interrelated persons, objects, ideas, and events and a "a set of interacting variables which is part of a larger system that is the sum of human experience". This can be viewed as a social-biological-engineering system. Management is the process of making effectuations to meet people's goals. All attributes of forest land which have value to human beings to meet a given need are termed forest resources. Resources change, by definition, as human needs and culture change. Thus, the very nature of forest resource definition includes value choices based upon social science concepts.

The approach suggested in this paper is to overcome the current overspecialization of academic forestry and the traditional biases of the forestry profession toward timber production, by transposing it to the realm of general systems analysis. Thomas Kuhn (1962) has studied the way in which new "paradigms" are created and old ones are destroyed; how paradigms are transmitted from one generation to the next; and how paradigms both help and hinder the progress of science. In particular, he distinguishes between "normal science"—working within the current paradigms—and "scientific revolutions"—in which the paradigm themselves come under assault. The ethnocentrism of belief systems mitigates against internal scientific revolutions within a discipline. Thus, "leading scientists" should be the least likely people to lead scientific revolutions. According to Weinburg (1975), Kuhn concurs in this conclusion as did Max Planck who wrote in his scientific autobiography:

> A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.

In forestry, the establishment of the paradigm of the next generation is now being influenced by current academic policy of the forestry and natural resource schools. The approach used by Duerr, Teeguarden, Christiansen and Guttenburg in their book on forest resource management is a step in the direction needed to develop the kind of generalist thinking for contemporary forestry and forest management. This book was the result of over 10 years effort and the combined work of 35 authors drawn from the forestry schools, agencies, and business concerns and from outside the forestry circle. Their contributions represented the array of specialized fields that constitute contemporary forest resource management. The authors state:

> A major a aim [of the book] is to focus the work upon integrated forestry: the creation and use of all the forest values from scenery to wood. We have tried to see forestry as a system of interacting variables and also a part of a larger social system

> that in the final analysis is the sum of human experience. Another aim is to view forestry, not as a set of rules, but as a set of resource alternatives. Still another is to demonstrate how modern quantitative methods of generating information can fortify judgement in choosing among resource alternatives.

This book is far from perfect. If nothing else the large number of contributors leads to a variety of writing styles and an uneven flow of the large number of subject areas presented. It also probably makes a large number of adherents to the traditional forestry paradigm uncomfortable. It is difficult to use as a handbook or textbook for traditional forest management concerns—cutting, planting, growing, and protecting trees. It could be said that the forestry profession cannot see the forest for the trees. It is the contention of this paper that the foresters should be the generalists, i.e., ones who know a variety of subjects and can integrate them into general laws of reasoning and systematic analysis.

Combined with the generalist approach to academic study and thinking should be the judicious use of quantitative techniques for management of information and decisionmaking about resource management and research. The development of sophisticated quantitative techniques combined with advances in computer technology provide a specialized means to generalize research and management methods. For example, Hafkamp (1986) has extended multiple layer programming methods to spatial, environmental and economic multiobjective decisionmaking. Kallio et al. (1986) presents a variety of articles revealing the state of the art of application of systems analysis techniques to problems of the forest sector. Care should be taken, however, not to excluded variables which are difficult to quantify or measure. Qualitative analysis can also be very useful for many problem and should not be rejected out of hand.

The advent of the computer and of prepared software packages has made modeling popular among scientists. However, the ease of use of many of these systems has allowed their indiscriminate use. The role and nature of modeling should be carefully examined. As Kac (1969) states about mathematical models:

> The main role of models is not so much to explain and to predict—though ultimately these are main functions of science—as to polarize thinking and to pose sharp questions. Above all, they are fun to invent and play with, and they have a peculiar life of their own. The 'survival of the fittest' applies to models even more than it does to living creatures. They should not, however, be allowed to multiply indiscriminately without real necessity or purpose.

This discussion can be applied to the construction of general system models (Weinberg 1975). There are essentially three sorts of activities related to models: (1) Improving the thought process—"to polarize thinking and to pose sharp questions", (2) studying special systems—real necessity or real purpose, and (3) creating new laws and refining old—"to invent and play with". The most important of these three is that of improving the thought process. The use of general systems principles provides an approach to learning which has certain categories of thought that because of their general nature supercede the particular vocabulary of a discipline, thus encouraging inductive reasoning and helping to remove disciplinary bias. Quantitative methods can also easily be incorporated into general systems analysis studies without regard for academic province.

## CONCLUSION

It is the contention of this paper that forestry is now in the process of redefining its paradigm i.e., belief system, to contend with what Wickstrom (1987) calls the post-modern world. He quotes Professor Dusan Mlinsek, past president of the International Union of Forestry Research Organizations (IUFRO) as stressing that forestry has reached a turning which requires it to escape from perceptions of nature as a closed system

that can be atomized and move into the post-modern perception of nature as a dynamic and totally integrated synergistic system. Mlinsek stressed the need for a holistic approach in forestry but recognized that the social aspects of forestry need particular attention if a holistic approach is to be achieved. He also acknowledged that institutional inertia has to be overcome in the process.

A modest proposal is presented here for an integrated holistic approach to the study of forestry. This includes the integration of various disciplines of study including social sciences into comprehensive framework of study. General systems analysis principles could be used to guide thought and action. Quantitative techniques could easily undergird special systems study without any particular disciplinary bias. The basic groundwork for this approach has already been laid by Duerr et al. (1979), albeit imperfectly. All that the forestry profession needs to do is to shed the old skin of its dying paradigm, step forward to become the generalists of conservation thought and natural resource study, and once again assume the leadership of the conservation movement in the brave new post-modern world.

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# OUTDOOR RECREATION RESEARCH AND PUBLIC POLICY: THE ROLE OF DISCIPLINARY BIASES

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**Abstract**. This discussion examines how disciplinary biases within outdoor recreation research can affect public policy. It suggests that important management tools adopted by outdoor recreation agencies reflect the perspectives of researchers with strong disciplinary roots in forestry. This perhaps has created a skewed perspective on what people are seeking from outdoor recreation, and on what it takes to produce a quality outdoor recreation experience.

## INTRODUCTION

Living organisms are, in part, products of their environments. This is hardly a revelation to those of us who conduct outdoor recreation research. It seems to be a principle learned long ago. For some of us, the revelation emerged during elementary lectures in forest ecology. For others, it was news conveyed through our earliest readings in social psychology. For most of us, such an observation is, quite simply, old news. In our frantic pursuit to develop new knowledge about outdoor recreationists and their quest, we are quick to dismiss such a proclamation as familiar and unenlightening.

Yet, it also seems that the full implications of this old truism have not been appreciated as we go about the task of producing outdoor recreation research. We have not recognized that we as researchers—just like the living organisms we study—are products of our environments. The concepts we create, the inferences we draw, the perspectives we yield, and indeed the truths we hold are, in part, products of our own particular experiential history.

And while the individual experience each of us has amassed empowers us with enriched perspective for solving problems confronted by recreation managers, it also acts to restrict our vision. We can become bounded by the perspectives of those who taught us; we can become shackled by the tenets of our own particular disciplinary heritage. We tend to be socialized to reflect the prevailing paradigms of the greater research community—rather than trained to break away from them. We tend to fail to see an alternate point of view.

## THE STRUCTURE OF RESEARCH

This discussion reflects upon some of our recent products of outdoor recreation research, and examines the role of disciplinary influences in affecting the character of those products. It suggests that disciplinary biases working within the research community are affecting how outdoor recreation management problems are being defined, how data are being interpreted, and even how scientific findings are being translated into management practice.

The fuel for such concern was precipitated, in part, by the review of outdoor recreation research presented by Knopf (1983). Through that review, a model of the forces impinging on the outdoor recreationist was constructed. In that model, the outdoor recreationist was posed as an actor subject to four discrete systems of influence—a social system, a personality system, a home and work system, and a cognitive system.

While the model seemed both theoretically sound and intuitively appealing, the question was raised whether the model accurately summarized categories of forces affecting the recreationist—or whether it did little more than reflect the organization of outdoor recreation research, which was broken into four lines of inquiry adhering to traditional disciplinary lines (Knopf 1983, p. 226). It

is possible, for example, that the concept of a social system emerged simply because there was a line of research being conducted by sociologists on the role of social forces in affecting outdoor recreation behavior. The concept of a personality system may have emerged simply because researchers in physical education and recreation health had concentrated on defining personality typologies of outdoor recreationists. The concept of a home and work system possibly emerged simply because researchers with a forestry perspective had developed a line of research on the motivating effects of conditions outside the recreation setting. And, the concept of a cognitive system may have emerged because yet another line of research was developed by geographers and cognitive psychologists who investigated the role of the mind in creating recreation experience. In Knopf's (1983) review, it seemed clear that different researchers with different disciplinary backgrounds were studying the same phenomenon, but were generating different messages about what forces are important in affecting outdoor recreation meaning.

The review left us with perplexing questions. Is our current understanding of outdoor recreationists and their preferences distorted by the discipline-bounded character of outdoor recreation research? Would our understanding of what is wanted by outdoor recreationists be different if research were to be organized to study meaning from a more holistic perspective? Four systems of influence were proposed, but are there missing systems? Are the boundaries between these four systems real? Or, do they do nothing more than reflect the broken character of recreation research—fractured by disciplinary lines across which there is little collaboration?

## IMPLICATIONS FOR POLICY

We now wish to carry such questions raised by the Knopf (1983) review to yet another level of analysis. If our current understanding of outdoor recreationists and their preferences is subject to distortion, might not also the public policy that is based upon that understanding be subject to distortion? Public land managers and planners have frequently searched for clues from researchers on how to produce quality recreation experiences. Based upon revelations from the Knopf (1983) review, it seems likely that the information researchers are forwarding to policy-makers is contingent upon the discipline they happen to be operating within. That is, opinions on what is important in terms of producing a quality experience depends upon what scientist a policy-maker might ask.

Consider, for example, the problem of recreation land classification. The currently popular Recreation Opportunity Spectrum (ROS) land inventory system—now adopted by two principal land management agencies in the United States—clearly has emerged from the work of researchers strongly influenced by the forestry disciplinary perspective (Buist and Hoots 1982). The ROS system suggests that variation in response to outdoor recreation settings is strongly linked to the character of physical setting. In particular, it suggests that variation in response is strongly linked to variation in the physical setting of a recreation locale along a primitive–urban continuum. It presumes there are six fundamental classes of outdoor recreation locales, organized along a spectrum: primitive, semiprimitive nonmotorized, semiprimitive motorized, roaded natural, rural and urban. These six classes are seen as the fundamental organizational framework for the distinction of recreation resources, are seen as delivering distinguishable forms of human experience.

While a nationally adopted planning methodology such as ROS has served well in fueling integrated recreation land planning, the presumptions underlying any such methodology must be examined for possible disciplinary influences. What would happen if a nationally adopted planning methodology were to spring forth from a discipline other than forestry? Would the presumptions remain the same that the fundamental source of variation in recreation response is associated with variation along a primitive–urban continuum?

Would the fundamental classes of outdoor recreation opportunity be the same? The answer to such questions may well be no.

For example, consider the character of a planning methodology that might emerge from the discipline of sociology. Rather that focusing on a primitive–urban continuum, it would probably distinguish among resources that facilitate different forms of social transactions. In fact, Cheek and Burch (1976) have proposed an outdoor recreation resource classification based upon stratifying resources by the character of transactions they evoke. They call for the creation of seven classes of outdoor locales based upon transactional function. The functions are: integration, bonding, solidarity, exchange, fantasy, transition, and custodian (p. 155). In their system, the social transaction variable emerges as the primary determinant of variation in recreation response. Yet, such a variable does not appear even as a secondary concept in the ROS planning methodology.

As another example, consider a planning methodology emerging from the physical education and recreation health discipline. It would more likely incorporate a classification of outdoor recreation locales based upon styles of personality that are serviced. Important discriminating variables identified in the past include: Active–passive, participant–spectator, control–noncontrol, and association–disassociation (de Grazia 1962). From such a discipline, one might doubt if primitive–urban variation would ever emerge as a primary discriminating dimension.

So the question emerges then—what is the primary discriminating variable that distinguishes among outdoor locales delivering different forms of recreation response? Is it truly the primitive–urban variable, which is the keystone variable upon which our national outdoor recreation planning methodologies are built? Or, do the presumptions of these methodologies merely reflect the disposition of foresters, who as a group personally and professionally tend to dwell on the city—nature distinction? What truly is the primary variable that outdoor recreationists pay attention to?

The possible tainting effects of disciplinary bias can extend into virtually every area where managers turn to researchers for assistance. Consider, for example, the concept of defining what is meant by a quality recreation experience. Several questions emerge. What does one mean by recreation quality? What are the important determinations of quality? What does a resource manager operate upon to enhance it?

Those with a forestry perspective have tended to focus heavily on elements of the physical setting as primary determinants of how recreationists feel about the quality of their experience. Quality is defined in terms of appropriate collections of rocks, trees, footpaths, facilities, insects, campfires, number of people encountered and other features that define the physical array (e.g., Rossman and Ulehla 1977). However, those with backgrounds in sociology have tended to define outdoor recreation quality as the degree to which a setting promotes a sense that people in that setting share similar values (e.g., Lee 1977). Those with backgrounds in physical education and recreation health have tended to define quality in terms of the ability of a setting to facilitate the expression of the personality of a recreationist ( e.g., Moss and Lamphear 1970). And, those with backgrounds in cognitive psychology might avoid any kind of emphasis on the external environment as a determinant of quality. Rather, they would define quality in terms of the symbolic or emotional constructs that are transpiring in the mind (Blomberg 1982).

So, what are the important determinants of a quality recreation experience? What does a resource manager operate upon to enhance it? The answers, again, seem to depend upon the researcher that is asked.

## CONCLUSION

This discussion points to the possibility that the world of science carries the potential for misdirecting public policy,

or at least for causing recreation resource managers to focus on issues that are different from those that are of priority to the recreating public. It may be that policy-makers are preoccupied with managing the physical setting, when what people really care about is the character of the social experience. It may be that policy-makers are preoccupied with managing the external environment, when what people really care about are the symbolic representations of those environments in their head—which may have little to do with the external array. As long as questions policy-makers ask of researchers yield different answers depending upon whom is asked, it is difficult to know if policy-makers are focusing on the right issues.

What is needed is a scientific community that engages in debate and critical analysis, and a resource management community that insists upon it. At present, researchers have been slow to cross disciplinary lines; they rarely acknowledge the work conducted by researchers external to their own discipline. Instances of rich, intense debate among outdoor recreation researchers are rare. In fact, there are sanctions against it. There is fear that the management community might then judge researchers as fickle, indecisive and therefore unreliable.

Yet, debate is precisely what the management community needs. There needs to be a willingness and commitments of scientists and policy-makers alike to open management concepts and procedures to scrutiny. Few efforts would advance the field of outdoor recreation more than to subject such central concepts in "land classification" and "recreation quality" to the rigors of critical analysis. There needs to be a classification of the fundamental differences of opinion; there needs to be a process for generating alternatives to the present point of view. Until we engage in a process that encourages us to imagine the alternatives, we will always carry the risk of misconstruing the true requirements of the recreating public.

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# INTERDISCIPLINARITY: BY CHANCE OR BY DESIGN

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**Abstract**. Interdisciplinarity may involve the active cooperation of scientists with different research interests and training, or the more passive transfer of ideas and concepts from one discipline to another. Transfer of ideas is usually an individual event, a chance event conceived in a well-prepared mind. A new idea is acquired fortuitously either while persuing relevant literature or while communicating with colleagues. Idea transfer precedes active cooperation. The idea is first conceived by an individual who may then seek either the advice or participation of others in reformulating the idea as a researchable problem. Innovative interdisciplinary research rarely arises by design. It must be initiated by an inspired individual.

# EFFECTIVE USE OF THE DELPHI PROCESS

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**Abstract**. The Delphi process systematically combines expert knowledge and opinions to derive a group consensus. It involves a selected panel of experts that share ideas and opinions through a series of questionnaires with feedback provided between rounds that summarizes the panel responses. It is applicable to problems that cannot be solved by precise analytical techniques, but a decisionmaker can benefit from the collective opinions of experts; more individuals are needed than can effectively interact in a face-to-face exchange; time and cost prevent frequent group meetings; or disagreements may be severe and communication must be refereed to avoid domination by strong personalities or by majority opinion.

The Delphi process has been used in forestry in several ways including allocating a forest fire prevention budget among various media; defining road construction standards for high mountain areas that would be acceptable to a wide array of interest groups; forecasting events in natural resource management and wildland recreation; estimating the loss in forest production from acid rain; formulating and analyzing county forest land policy alternatives for funding, timber sale procedures, and land ownership and forecasting ecological and institutional change in the Lake States forest environment.

Makeup of a Delphi panel varies with the problem to be addressed but may include experts, stakeholders and facilitators. Problems may arise in identifying experts and getting their commitment to participate. Other problems with the Delphi are the long time periods often needed for the study, panel drop-out, editing panel responses and feedback by the study director, tendency to treat future events as independent of one another, the large amount of time needed by the director to conduct the study, and difficulty in determining reliability of results.

## INTRODUCTION

The delphi process enables a group of individuals, usually experts, to communicate with one another while retaining anonymity. This group process is usually aimed at exploring complex problems and often involves generating alternatives, evaluating impacts or forecasting future events. This panel of experts usually interacts through a series of questionnaires. Feedback is given between rounds in the form of a summary of panel responses to the former questionnaire. This feedback enlarges each participant's view of the situation. Panel members usually have an opportunity to revote on items after seeing the group response.

The delphi concept originated in the early 1950's as a spinoff from defense research by the Rand Corporation (Dalkey and Helmer, 1963). It was introduced to a broader research community in 1964 with publication of Gordon and Helmer's Rand paper, "Report on a Long-Range Forecasting Study".

It has been used thousands of times for a wide variety of problems. Its most common use has been for technological forecasting. How does "forecasting" fit into the array of means for projecting the future? Bunge (1967, pp. 66)) defines five means of forecasting the future:

1. Expectation: an automatic attitude of anticipation found in all higher animals.
2. Guessing: a conscious but nonrational attempt to figure out what is, was, or will be the case without any ground whatever.
3. Prophecy: large scale guessing on the alleged ground of revelation or other esoteric source.

4. Prognosis: an informed guess or common-sense prediction with the help of more or less tacit empirical generalizations.
5. Scientific Prediction: forecast with the help of scientific (or technological) theories and data.

The delphi process is designed as a means of "scientific prediction". Panel members apply known theories and data to complex problems. It is applicable to problems which exhibit one or more of these properties: (Linstone and Turoff, 1975, p. 4).

A. A problem does not lend itself to precise analytical techniques, but a decision maker can benefit from subjective judgments on a collective basis.
B. More individuals are needed than can effectively interact in a face-to-face exchange.
C. Time and cost make frequent group meetings infeasible.
D. The efficiency of face-to-face meetings can be increased by a supplemental group communication process.
E. Disagreements among individuals are so severe or issues so politically sensitive that the communication process must be refereed and anonymity assured.
F. To assure validity of results there is a need to avoid domination by the majority or by strength of personality.

The delphi process has been used a number of times for forestry related problems, including the following:

A. How should a fire prevention budget be allocated among various media to have the greatest effect on reducing the number of forest fires in Alberta (Dunn, Harnden, Newton, 1974)?
B. What criteria should be used to design and construct roads in alpine areas of Germany to satisfy diverse interest groups (Gundermann, 1978)?
C. What policy alternatives and policy impacts should be considered by Minnesota county governments with respect to funding forest management, determining what land to retain in public ownership, and selling timber -- especially long term leases (Baughman, 1982)?
D. What major events are likely to occur in the next 25 years that will influence the natural environment in the U.S.? Events were grouped into 5 categories: natural resource management, wildland- recreation management, environmental pollution, population-workforce-leisure, and urban environments (Shafer, Moeller, Getty, 1974).
E. What is the most likely percentage change in forest productivity in Canada due to long range transport of air pollutants (Fraser, 1985)?
F. What will be the demand for recreation resources in the area around Bemidji, Minnesota, in twenty years (Beliveau, 1981)?
G. What combination of land management strategies in a particular U.S. Forest Service planning unit will produce the least conflict among special interest groups (Freeman, Tremaine, Madson, 1977)?
H. In the Great Lakes forest region, what key variables will affect ecological and social changes over the next 20 years and what policies could be used to guide future change in the region (Flader, Bonnickson, Jordahl, 1980)?
I. What combination of land uses are most appropriate for Minnesota's State Forest lands (Knopp and Caldbeck, 1985)?

## DELPHI COMPARED TO POLL AND COMMITTEE

The delphi is a hybrid between a public opinion poll and a committee meeting. It is similar to a poll in that it involves having a group of individuals independently and confidentially respond to a questionnaire that seeks personal opinions about a problem area. It differs from a poll by the feedback of information provided to respondents and the opportunity for individuals to modify their judgments based on their reaction to the collective views of the group. The delphi often involves a smaller respondent group than a poll, but requires a longer time period to secure responses. Since delphi panels are usually carefully chosen and the

members interact through the medium of a questionnaire with feedback, the panel responses are not a random sample from a population, and many statistical tests that would be applied to data from a poll are not appropriate for a delphi.

A delphi is similar to a committee because it often involves a relatively small group of carefully selected people that exchange ideas in the process of dealing with a problem. It differs from a committee by not permitting face-to-face meetings of the participants. Delphi avoids some of the psychological characteristics of a committee process including:

- -The domineering individual that takes over the committee process.
- -The unwillingness of individuals to take a position before all the facts are known.
- -The unwillingness to abandon a position announced publicly.
- -The difficulty of publicly contradicting individuals in higher positions.
- -The fear of bringing up an idea that might be considered idiotic by others.

## DUTIES OF SPONSOR, MONITOR, PANEL

A delphi process often involves three sets of actors—a sponsor, monitor and panel. The sponsor may be an individual, an organization, or several organizations that require analysis of a complex problem. The sponsor should be involved in the study design to ensure that relevant problems will be analyzed. The monitor is responsible for coordination with a sponsor; choosing a panel; questionnaire design, analysis and feedback; budgeting and a final report. Ideally, the monitor should be a team of at least two individuals—one knowledgeable about the problem and one with study design and editorial talents (Turoff, 1970). Depending on the nature of the problem, the panel may consist of three types of participants—stakeholders, experts, and facilitators. Stakeholders are people directly affected by the problem and those who will use the study results. Experts have special knowledge or experience relevant to the problem. Facilitators have skills in clarifying, organizing, synthesizing and stimulating. They may be chosen to represent diverse views (Scheele, 1975).

Panel members are seldom selected at random, but rather are carefully screened and selected because of special knowledge or skills they can contribute to problem analysis. It may be appropriate to identify three or four subgroups in the panel and keep track of how different subgroups vote on specific items. If a logical group of panel members is not readily identifiable, the monitor should solicit nominations from the sponsor, from panel members selected early in the planning, and from key persons knowledgeable about the issue. Invitations to participants are often sent in letter form, but personal meetings or telephone calls will probably yield a higher rate of acceptance.

Panel size can vary from a few individuals to several hundred members. Small groups are suitable for deriving a consensus on a few, very specific, technical questions. For example, a delphi panel of three people estimated the number of elm trees that would be killed by Dutch elm disease in Minneapolis, Minnesota in the following year. Very large groups are appropriate when public involvement and education are prime motives, but deriving a consensus is not important. An example was the study aimed at determining the types and amounts of different land uses that should be permitted on Minnesota State Forest lands (Knopp and Caldbeck, 1985). The initial mailing list had 1,159 names, but the dropout rate was high. Depending on the types of questions asked in the delphi exercise, the second round can generate five to ten times as much information as the first round (Turoff, 1970, p. 92). This snowball effect can quickly overwhelm a monitor as well as the panel. The time required for a monitor to summarize responses and for a panel member to react to the feedback may place limits on panel size. However, in a delphi study with 118 topic statements, there was no change in variance in responses between the first and last pages of this long questionnaire. The author interpreted this to mean there was no panel fatigue (Huckfeldt and Judd, 1974).

Motivation of panel members to continue through the delphi process requires careful attention (Scheele, 1975). Panelists—particularly those with technical backgrounds—must be convinced that judgments often have to be made about issues before all the facts of the problem have been researched and analyzed to the extent they would like. They must be persuaded that their subjective judgments may be a decision makers most valuable source of information. If panelists may be disinterested, find a worthy or prestigious sponsor or make participation of significant publicity value. Panelists must be convinced that time will not be wasted on obvious aspects, that subtleties in responses are understood and appreciated. Attractive and stimulating peers are probably the most powerful incentives for participation. Delphi is very demanding. Respondents should be recognized as consultants and properly compensated for their time with an honorarium, gift or "in-kind" reward if the delphi is not an integral part of their job function.

## QUESTIONNAIRE DESIGN

Questions posed to delphi panelists may be presented in one of several formats. In most cases panelists work on written questionnaires sent through the mail. It is also possible to have respondents reply via computer terminals to speed up transmission of information and summarization of responses. Tape recorded responses or personal interviews may also be used.

Questionnaires should be carefully designed to achieve reliable and valid information. They should be pre-tested by persons knowledgeable about questionnaire design and by persons similar to the panel members in background. A month or more may be needed to develop the first-round questionnaire (Turoff, 1970, p. 43). Questionnaires for succeeding rounds should be designed before the first questionnaire is sent to the panel in order to be assured that the information received in one round can be adequately summarized and integrated into succeeding rounds.

How many rounds of responses are needed? Brockhoff (1975) found that on almanac and short range forecasting questions, where panel members were faced with the same set of decisions in each round, there was variance reduction in every round up to the fifth round, but the best results were already known in the third round. There may be a need for more than three rounds if the panel deals with a different set of tasks in later rounds.

The quality of materials sent out reflects the significance of the inquiry (Scheele, 1975). Give materials style, color and quality printing. Use emotive language and vernacular expressions to engage panelists. It may be appropriate to provide respondents two copies of the questionnaire so they may retain one for later reference or to do rough work (Turoff, 1970).

In the first round a factual summary of background material may be provided to panelists so they all start with the same basic level of knowledge about key facts (Turoff, 1970, p. 93). In consideration of the time required to assimilate this information, the background material should not be overwhelming.

Delphi exercises often start with open-ended questions to capture creative ideas or insights. Panelists new to delphi may respond with compound and sometimes lengthy comments. It is a good idea to show them examples of the form that comments should take in terms of being short, specific and singular in nature (Turoff, 1970, p. 93). Statements describing future events should be twenty to twenty-five words in length to achieve the highest consensus in forecast dates. Lower and higher numbers of words yield low consensus (Selancik, Wenger, and Helfer, 1971). The monitor must not impose his views and preconceptions of a problem upon respondents by overspecifying the structure of the delphi and not allowing for contributions from other perspectives related to the problem.

Standardized scaled measures should be available to respondents so they can qualify their responses to specific questions. Rating scales, such as a Likert

scale, are often used to measure relative importance of issues, desirability and feasibility of alternatives, probability of occurrence of events, confidence of respondents and the respondent's selfmeasure of expertise. Such rating scales permit rating one item at a time. They are quick, easy to comprehend, and psychologically comforting. By contrast, the pair comparison method is time consuming, requiring forty-five judgments for a comparison of ten items. The ranking method is fairly easy for a small list but increasingly difficult for a longer list. Participants may get frustrated by not being able to give equal rank to some items.

When editing respondents comments for clarity, try to preserve the intent of the originator. When editing from round to round, avoid changing a statement so that it has one meaning in round one and another in round two (Goldstein, 1975). Personal comments and arguments by respondents should be part of the information feedback.

On some issues selected panel members may contribute more expertise than other panel members. It is fairly common to ask panel members to self-rate their expertise on each issue. It was verified in one study on almanac-type questions that self-rating is a meaningful basis for identification of expertise and that selection of expert subgroups improves accuracy to a greater degree than feedback or iteration (Dalkey, Brown and Cochran, 1970). In another study (Brockhoff, 1975) self-ratings of expertise improved accuracy in only two of four delphi panels dealing with almanac and short-term forecasting questions. Expertise on specific issues did correlate with the number of years spent in a profession and with experience in a particular field related to the issue. There was no adequate measure of expertise for very specific questions.

Statistical analysis of the responses provides useful insights. When rating scales are used, the median and interquartile range (IQR) are commonly fed back to participants. Panelists are often shown their vote from the previous round and are given a chance to revote. Panelists outside the IQR are often asked to justify their answers. The median is used rather than the mean to reduce influence by outliers.

We cannot forecast behavior of the whole by forecasting behavior of its parts. Interactions and secondary events must be considered. Cross-impact analysis is a potentially valuable method for revising estimated probabilities of future events in terms of estimated interactions among those events. A delphi panel can determine initial probabilities and estimate an interaction matrix (Dalkey, 1972, p. 327).

By the third round, frequency distributions of responses should point out which items exhibit a polarized distribution, a flat distribution, or which items respondents are unable to make judgments about. The monitor should solicit additional comments on the latter items. Since delphis strongly tend to induce convergence and agreement, the monitor should purposely introduce ambiguities, even disruptions to act as a catalyst to explore the limits of alternatives. Agreements about a recommendation should be explored to discover whether individuals agree for the same reasons or not. Likewise a monitor team which ignores disagreements may cause discouraged dissenters to drop out thus creating an artificial consensus (Turoff, 1970, p. 88).

Convergence of responses is more common than divergence over several rounds. There is also a strong tendency for increased opinion change by individuals far from the median. In one delphi the feedback was purposely altered to move the mean response. Panelists were influenced by the new mean and shifted toward it. This seems to indicate that most respondents are interested in the opinions of other members of the group and desirous of moving closer to a perceived consensus (Scheibe, Skutsch and Schofer, 1975). In this same vein a highly dogmatic group is less likely to change an answer to a question on which they consider themselves expert than one on which they consider themselves less expert. But, in the presence of some perceived authority, such as a group

median, high dogmatism groups exhibit more change than low dogmatism groups (Mulgrave and Ducanis, 1975).

It is common to have the panel predict future events in a given time frame and estimate the date of occurrence or a probability estimate of the date of occurrence of events. Previous research indicates that short-range forecasts tend to be optimistic, but long-range forecasts are frequently pessimistic (in the long term no solution is apparent) (Martino, 1970a). Panelist uncertainty increases as the median date of an event moves further into the future (Martino, 1970b). We also tend to discount or not relate well to events in the distant future or in distant places (Linstone, 1973). The delphi designer should try to develop scenarios within the planning horizon of the panel. Perhaps the monitor can find a similar event already occurring somewhere else which can be described to compress the time dimension. The monitor could try to bring respondents into the future by having them role play in the future (Scheele, 1975).

We have a natural tendency to seek predictions about which there is strong agreement. We have more confidence in predictions which panelists strongly agree have a 50-50 chance, than predictions with a 70-30 chance but a high degree of divergent opinion. The latter we often consider unreliable (Linstone, 1975, p. 578). A strength of delphi is its ability to expose uncertainty and divergent opinion.

## RELIABILITY OF DELPHI

An appropriate question about the delphi process is whether or not two panels addressing the same problem will produce similar results. There is evidence to support the reliability of delphi. Dalkey took first round answers to almanac-type questions and drew different sized subgroups of the entire panel to determine if the group median answer differed among the subgroups. He concluded that with an expert panel no larger than fifteen, it is highly unlikely that another equally expert panel will produce a radically different mean (Martino, 1972, p. 49). Gundermann (1978), at the conclusion of a delphi study, randomly divided an expert panel into two subgroups and compared responses with two statistical tests. He concluded the tests showed that the delphi results were reliable. Other studies comparing the forecast dates for future events obtained from different delphi panels show similar and therefore reliable results (Ament, 1970; Bender, et al., 1969; Martino, 1972, p. 50). Reliability probably depends more on questionnaire design and wording as well as selection of comparable delphi panels for comparison than upon the nature of the delphi process itself.

## VALIDITY OF DELPHI

Persons considering use of the delphi method are interested in its validity or the accuracy of its predictions, especially when compared to other methods of prediction. Controlled experiments have been done in which delphi panelists were asked to estimate "almanac-type" data, where the experimenter knew the correct answer. Panel members did not know the answer, but had enough background information that they could make an informed estimate. Furthermore, delphi panels were compared to face-to-face panels. More often than not, the group median was improved by the anonymous feedback in the delphi process, while it became less accurate by face-to-face interaction (Martino, 1972, p. 32). In a forecasting experiment, college students were asked to estimate the point spread for two upcoming football games. Participants had access to information on previous performance of the teams and their players. A delphi and a committee process were conducted simultaneously with different groups. Results of the delphi process were more accurate than the committee process in forecasting point spreads (Riggs, 1983). Several studies have concluded that the degree of uncertainty felt by the panel increases as the time length of the forecast increases. In other words, panel forecasts are more dispersed as the time length of the forecast increases (Martino, 1970b,1972, p. 44).

**POTENTIAL PROBLEMS**

There are potential problems in using the delphi process that users should be aware of. An individual asked to list his preferences on paper may give a significantly different response from that which he would give in a real-life/real-time setting. A reasonable sounding (surprise free) scenario is usually judged "more likely" to occur than an unfamiliar one even if there is no evidence to support such a differential evaluation (Linstone, 1975, p. 575). A panelist may be unable to communicate in a concise sentence or diagram. Panelists may reply hastily without adequate thought or without reference to available materials. A specialist may not be the best forecaster if he is accustomed to focusing on a narrow field or subsystem and not taking into account the larger system and its interactions. Repeated delphis on the same subject can use up experts, or respondents that are familiar with prior studies may regurgitate old ideas. A panel of experts may not exist in some areas. All respondents and designers have biases both conscious and unconscious.

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# ORGANIZATION THEORY AND FOREST MANAGEMENT: PROSPECTS FOR COLLABORATION

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**Abstract**. Much of the world's forest management is carried on through organizations. To a large degree, the effectiveness of forestry activities depends upon both the arrangements of people and tasks in an organizational setting; and on relations that develop among organizations in pursuing their specific objectives. Understanding these social phenomena may enhance the potential for effective forest management in organizations and society alike. This paper considers the relevance of organization theory to forest management. Following a brief description of three organizational studies of a public forestry agency; different theoretical perspectives of organizations are outlined within a metatheoretical framework designed to differentiate scope of analysis and behavioral assumptions. The above studies are then considered within this classificatory scheme; and areas likely to be important in future research on forestry-related organizations are also suggested.

"Policy is enunciated in rhetoric; it is realized in action." So began Herbert Kaufman's 1960 work **The Forest Ranger**, a classic study of administrative behavior within the U.S. Forest Service. Prior to 1970 it was one of the few studies of its kind with respect to formal organizations in the public sector.

The Forest Service is but one of a number of different kinds of organizations concerned with forestry in the United States. This diversity in turn reflects an entire social landscape that is made up of organizations. The organization is a major vehicle for getting things done in society, whether it be labor or leisure. The best technology, the finest growing stock, the sharpest technical experts, even unlimited funding lie relatively dormant without an effective organization through which they may be activated.

One would expect that a public agency, an interest group, a forest products firm, a research unit, and so on would be structured differently; made up of members with different skills and interests; and would engage in forestry-related activities in different ways. Knowledge of these organizational forms and actions would likely aid managers and others in better understanding the complex social relationships in which they are involved.

This paper describes the developing field of **organization theory** as one tool for fostering such knowledge. The paper begins with short sketches of three organizational studies of the U.S. Forest Service, spanning a period of three decades of agency activity. Attention then turns to a thumbnail sketch of the structure of organization theory, utilizing a recent metatheoretical framework within which differing perspectvies may be classified. The final section of the paper considers the above forestry-related studies within this framework; and offers some thoughts concerning the relevance of organization theory to understanding the nature and management of forestry-related organzations of all types.

## ORGANIZATIONAL STUDIES OF A PUBLIC FORESTRY AGENCY

Herbert Kaufman introduced his 1960 work by observing that it is often assumed that the goals established by the top eschelons of organizations will be translated more or less automatically into specific actions at the local level. He noted that within the U.S. Forest Service, the degree of compliance of field administrators with directives from above, while not complete, was so significant as to beg for an explanation. His study was thus to be concerned specifically with "the way the field men are

induced to carry out tangibly the terms of headquarters agreements" (p. ix)[1]

The author focused upon the pivotal role of the district Ranger as administrator of the agency's operational or field-level unit. He selected five districts in different parts of the country for intensive analysis. He visited each, gathering information through interviews with Rangers, examination of documents, and so on.

Kaufman observed that despite the efforts of the Forest Service to promote consistency in management on all districts; it is unavoidable that the substantive content of the agency program is shaped by the daily activities of the district Rangers. Carrying out their various functions necessarily involves interpreting the nature of their jobs; and as a result "Rangers in effect modify and even make policy — sometimes without knowing it" (p.65).

The author then identified a number of "challanges to unity" resulting from the significance of personal and local factors on district management. These were seen to act as 'centrifugal forces' tending to disrupt the intended coherence between field units and upper management levels. These *impulses toward fragmentation* included: a) Problems of internal communication, reflecting social and geographical distance of Rangers from superiors, as well as the former's need for reconciling general instructions with specific situations; b) The potential 'capture' of field officers by local populations, either through Rangers' identification with local interests or their reactions to local political pressures; c) A Ranger's personal predilections or predjudices not being in harmony with objectives of organizational leaders; and d) Influence of the Forest Service's ideology of decentralization, which places high value on assertion of independence, autonomous decision-making, and defense of local and personal points of view. Unchecked, these influences would seem to have the potential to result in such variation in the substance of local programs as to "destroy (the Forest Service) as an integrated, functioning organization" (p.87).

Kaufman then examined why this did not happen. He identified a number of *techniques of integration* established by central Forest Service officials to preserve and enhance organizational unity. In brief, the agency attempted to: a) Institute a variety of procedural devices for preforming decisions, including authorizations, directives, prohibitions, clearances, etc.; as well as financial and workload planning procedures; b) Discourage deviations from these decision procedures via direct control mechanisms such as field reports, daily diaries, and inspections; hearings for public appeals; movement of personnel (to reduce potential for capture by local interests); and formal sanctions; and c) Internalize organizational goals and values by selecting, training and socializing personnel in ways conducive to maximizing organizational identification. Such an internalization of values may then in effect render direct controls unnecessary by fostering voluntary compliance of district Rangers with agency objectives.

Kaufman concluded from his study that for the Forest Service of 1960 the techniques of integration had been effective (p.206); and that the impulses toward fragmentation had for the most part been overcome. Overall performance did not differ significantly from goals established by agency leadership; and other symptoms of distress in relations between Rangers and higher management levels were for the most part absent. The author found the most striking evidence of effective integration to be reflected in the similarity of the Rangers' perspectives on a wide array of aspects that were part of their professional, and to a lesser degree, personal lives.

At the same time, Kaufman warned that excessive 'homogenization' of Rangers could inhibit creative input from the field level. In addition, he cited numerous forces for change which, from the agency's perspective, suggested that integrative techniques cannot remain static.

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[1] Page references to Kaufman's work refer to the 1965 (paperback) edition of the **The Forest Ranger**.

In short, "these ever-changing conditions mean the methods of one decade may not be sufficient in another. The challanges to unity never disappear; they can only be held in abeyance" (p.209).

**The Forest Ranger Revisited**. Twenty years later Christopher Leman returned to the five districts Kaufman had studied and interviewed the Rangers then in charge. He also interviewed 106 additional agency personnel at all levels of management; as well as the five original Rangers in Kaufman's study, all of whom had left the agency. Given the enormous increase in demands for forest outputs, far-reaching new laws, and technological advances in land management and information processing; it is not surprising that the author found a different world on the Forest Service district entering the 1980's.

In a 1981 paper entitled **The Forest Ranger Revisited**, Leman observes that the Ranger is now in effect the manager of a "miniature bureaucracy" — with many more subordinates, a large number of whom are specialists. The district must now supply a substantial amount of information as inputs to Forest-level planning activities at the National Forest Supervisor's Office; while having to complete ever more detailed operational and work plans for the district. Leman finds that there has been a shift in the focus of controls within the agency from a number of the direct techniques described by Kaufman to those exercised through these planning and budgeting processes. The agency also relies more on professional standards as controlling mechanisms for foresters and specialists alike.

The author finds that, on the whole, the Rangers believe they still maintain a fair degree of autonomy regarding intra-district allocation of goals assisgned to the district from above, and some input into the determination of the latter. In a sense the sheer complexity of their job would seem to make it even more difficult for excessive oversight from higher management levels. Leman concludes that the techniques for integration, though altered from past decades, remain operative; and that the Forest Service remains "one of the most successfully decentralized bureaucracies in the world". At the same time, he warns that the massive informational and analytical requirements of the planning process may reflect an attempt to accomplish the impossible; and that input from the field level remains critical to preventing these requirements from fragmenting the congruence of Rangers' attitudes with central agency policy that has characterized the agency for the last three decades.

**Interest Group Influence**. One implication of Kaufman's study was that the relatively high degree of compliance by district Rangers with central agency policy — as obtained via the formal and informal agency practices he described — would lead Rangers to *conform* to that policy even in the face of efforts by various interest groups (particularly at the local level) to convince the Ranger to act otherwise. In traditional theories of public administration, it is generally viewed that such conformist behavior is appropriate to lower-level agency managers. This still involves interacting with interest groups, but in a manner in which agency policy is preserved.

An alternative perspective, articulated by McConnell (1966), argues that interest groups are narrow and localized in their perspectives; and that in order to maintain support, government agencies institutionalize group access to land management decision processes. The ultimate effect of these relations is that the agency becomes *captured* by the clients it serves — the very result Kaufman describes the Forest Service as having successfully avoided.

Paul J. Culhane examined this "capture-conformity" debate in his 1981 work **Public Lands Politics**. He selected three geographical areas in the United States and interviewed Rangers on all 28 districts of the four National Forests located in those areas. (Officials of local field units of the Bureau of Land Management were also interviewed). He collected information on district resources and outputs; and personal characteristics of Rangers, including their memebership in other organizations. He

also identified about 40 different types of organizations involved in local federal lands politics in the three areas; and operationalized measures of group values, power, and access to land management decisions on Forest Service districts.

Culhane then identified the interest group contacts of Rangers, in effect defining an **organization-set** (Evan, 1966) for each administrator. He constructed a typology of sets based on the relative prevalence of four key types of groups — forest products firms; livestock operations; mining firms; and conservationists and recreationists. Culhane sought to test the "capture thesis" via the premise that if it were true then "the policies of Rangers ... with one type of organization-set should be significantly different from those of their colleagues with a different type" (p.195). He did not find this to be the case. In addition, most Rangers displayed sufficient variation in the composition of their sets "to maintain reasonably balanced constituencies" (p. 196). The author posited that this *variation within organization sets* was a more important factor in precluding capture of Rangers by interest groups than was their *conformity* to agency policy, the latter being that factor to which Kaufman had attributed causal priority (p.226).

## OVERVIEW OF ORGANIZATION THEORY

Both Culhane and Kaufman examined the same organization, but each employed slightly different conceptual lenses in so doing[2]. Kaufman stated at the outset of his work that he did *not* intend to focus on substantive policy problems, techniques of organizational survival, or bureaucratic politics; and that, with respect to what he wished to examine "it makes no difference whether what is done by the Forest Service is ... or is not ... what it should be doing" (p.x). Culhane observed early on that "interest group theories of politics provide an ideal framework for examining federal public lands management" (p.22).

How does Kaufman's viewpoint differ from Culhane's; and, just as importantly, how are they related? How many ways are there of looking at an organization such as the U.S. Forest Service? The answer to the second question is deceptively simple: there are as many ways to look at the agency as there are people willing to take the time to do so. At the same time, there are certain ways which qualify for inclusion under the heading of 'theoretical perspectives'; and the 'field' within social science which deals with the nature and construction of theories of organizations is referred to, appropriately, as **organization theory**. This section briefly discusses a metatheoretic perspective within which the structure of this emerging field may be articulated. The following pages then consider the perspectives of the above authors with the aid of this conceptual framework.

The scheme to be described here is that developed by Van de Ven and Astley (1981) and Astley and Van de Ven (1983). It is presented in Figure 1. Two key factors provide the underlying rationale for the classification of theoretical perspectives: a) the level of organizational analysis; and b) the relative emphasis placed by the theories on deterministic versus voluntaristic assumptions about human nature.

The level of organizational analysis may be viewed in terms of what the authors call a *micro-macro* distinction between the organizational characteristics under study. This makes explicit the fact that any type of collective structure or behavior is characterized by relations between the parts and the whole. At the same time, the 'whole' at one level is a 'part' of the next higher level. Thus within organizational analysis there exists a series of part-whole relations spanning levels from individual, group, unit, division, organization, population, and so on.

In Figure 1 the authors identify the micro level as including individual organizations and the people and/or positions within them. The macro level focus is upon populations or networks of organizations. As indicated above, the selection of these two particular levels (e.g.,

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[2] Leman's theoretical perspective mirrors, understandably, that of Kaufman.

**Perspectives and Debates**

| | DETERMINISTIC ORIENTATION | VOLUNTARISTIC ORIENTATION |
|---|---|---|
| MACRO LEVEL (Populations and communities of organizations) | NATURAL SELECTION VIEW<br>*Schools:* Population ecology, industrial economics, economic history.<br>*Structure:* Environmental competition and carrying capacity predefine niches. Industrial structure is economically and technically determined.<br>*Change:* A natural evolution of environmental variation, selection and retention. The economic context circumscribes the direction and extent of organizational growth.<br>*Behavior:* Random, natural, or economic, environmental selection.<br>*Manager Role:* Inactive. | COLLECTIVE-ACTION VIEW<br>*Schools.* Human ecology, political economy, pluralism<br>*Structure:* Communities or networks of semiautonomous partisan groups that interact to modify or construct their collective environment, rules, options. Organization is collective-action controlling, liberating, and expanding individual action.<br>*Change:* Collective bargaining, conflict, negotiation, and compromise through partisan mutual adjustment<br>*Behavior:* Reasonable, collectively constructed, and politically negotiated orders.<br>*Manager Role:* Interactive. |
| MICRO LEVEL (Individual organizations) | SYSTEM-STRUCTURAL VIEW<br>*Schools:* Systems theory, structural functionalism, contingency theory.<br>*Structure:* Roles and positions hierarchically arranged to efficiently achieve the function of the system.<br>*Change:* Divide and integrate roles to adapt subsystems to changes in environment, technology, size, and resource needs.<br>*Behavior:* Determined, constrained, and adaptive.<br>*Manager Role:* Reactive | STRATEGIC CHOICE VIEW<br>*Schools:* Action theory, contemporary decision theory, strategic management.<br>*Structure:* People and their relationships organized and socialized to serve the choices and purposes of people in power<br>*Change:* Environment and structure are enacted and embody the meanings of action of people in power.<br>*Behavior:* Constructed, autonomous, and enacted.<br>*Manager Role:* Proactive. |

Figure 1. Four Views of Organization and Management. (Source: Astley and Van de Ven, 1983)

organization — population) is not the only one they could have made; they did so because for their purposes this distinction works best for the classification of theoretical perspectives on organizations.

The second analytical axis in Figure 1 derives from the age-old philisophical problem of free will, which is essentially concerned with the basic nature of human action. Do human beings and the institutions they create act autonomously, shaping their environment according to proactive choice; or are their actions determined exogenously by social forces too powerful for individuals or their institutions to influence or change?

A voluntaristic theoretical orientation, accepting the former view, depicts individuals as directing their own pursuits, and therefore as the basic source of change in organizations. In contrast, a deterministic perspetcive views the human individuals and institutions as embedded within a social structure which constrains autonomous action to a significant degree. While this does

contribute to stability in institutional and organizational arrangements; individuals and institutions find themselves having to react more to exogenous societal conditions than capable of autonomously creating their own social reality. The authors note that social determinism and individual freedon represent polar extremes for classifying theoretical approaches to organizations; and that most theories are more moderate in their positions than can be depicted in this scheme. Nonetheless, the distinction touches at the heart of nature of organizations — how human actions come to be arranged for the attainment of particular ends.

A brief overview of the four theoretical orientations depicted in Figure 1 is now in order. A **systems-structural** perspective is perhaps the most traditional of those represented therein. It reflects the synthesis of structural-functionalism (Parsons, 1975), the dominant paradigm in American sociology through the 1960's; and open systems theory (Katz and Kahn, 1978). Both view organizations as systems in which certain critical activities or functions must be fulfilled to insure survival. In Katz and Kahn's framework, for example, key organizational functions include production; production-support (input acquisition and output disposal); maintenance (motivation of members); adaptation; institutional relations; and management of the system.

Functions, therefore, become goals of the system which are attained via the creation of specific structures. The structure of the system is manifest in the arrangement of its functional subsystems, of which the basic structural component is the *role*. A role defines a set of behavioral expectations and responsibilities for the individual who occupies it; and positions in the organization are comprised of a number of roles. The content of the role is derived from its location in the subsystem, which is articulated as an input-output transformation process. Thus, for example, a forestry technician would have a number of roles within the agency's production subsystem.

The basic managerial tasks in this perspective involve *differentiating* the structure of the system to adapt to variations in elements of the environment on which the system depends for survival, i.e., is contingent (Lawrence and Lorsch, 1967); and *integrating* the more complex structure in a manner most conducive to the attainment of organizational goals. Organizational behavior is thus seen to be constrained and manipulated by top management, whose behavioral options are themselves largely dictated by changes in the organization's environment to which they must react appropriately.

A **strategic choice** perspective at the micro-level of organizational analysis is an outgrowth of social action theory (Dawe, 1978). This area of sociology has focused on the meanings which individuals assign to conditions around them and the interpretations derived therefrom as the driving forces of social action.

Within organization theory this approach has been developed from the initial works of Silverman (1970) and Child (1972). The latter has placed particular emphasis on the fact that the interpretations of reality noted above often have a distinctly political dimension. Reacting to the deterministic implications of systems theories, this perspective argues that decisions about organizational structure are not simply responses to contingencies imposed by the environment or by some set of internal system needs; but are "strategic events that include reference to the value positions of the actors involved and to the political processes in which they engage" (Van de Ven and Astley, 1981:436).

In this light roles do provide a framework for action; but within them individuals interact to construct their own definitions of situations; and act upon these 'social constructions of reality' (Berger and Luckman, 1966) to transform organizational structure for specific purposes. Managers are not reactive but *proactive*, both in designing organizational structure and in interacting with the environment. With respect to these external relations, resource dependency

theory (Pfeffer and Salancik, 1978; Pfeffer, 1981) posits that while environments do impose constraints, they can be manipulated through political negotiation to fit the objectives of those in power within the organization.

Shifting the level of analysis to that of populations of organziations, a **natural selection** orientation adopts this dominant paradigm in the biological sciences to the study of structural characteristics of populations of organizations — i.e., communities, industries and even society. Within a population ecology perspective (Hannan and Freeman, 1977; Aldrich, 1979) the basic evolutionary processes of variation, selection and retention are seen to operate on organizational forms. In effect, the forces of environmental competition and carrying capacity drive the evolutionary process that shapes the structure of the population. This viewpoint has a clear counterpart in theories of industrial economics, in which firms (or entire industries) that cannot compete successfully or gain access to scarce resources are 'selected out'; while those that fill the niches the environment provides will survive. Given such powerful forces at work, these theories posit a relatively inactive role for managers — who, while they may exert some influence through symbolic leadership, are essentially powerless to stem the tide of environmentally- driven change.

Within the natural selection perspective, particular organizations or 'elements' of the population are viewed as relatively similar and mutually vulnerable to environmental influences. A population is thus a simple aggregation of its individual members. In the **collective action** perspective, however, the identity of the population derives from its 'organization' as a network of semi-autonomous organizations who purposively join together as a social action system. Such a network manifests emergent properties not found in any of its members; and must therefore be examined at a macro or population level of analysis.

In this perspective, organizations are not seen to be pitted individually against a natural environment in fighting for survival; but as "emphasizing collective survival, which is achieved by collaboration between organizations through a construction of a regulated and controlled social environment that mediates the effects of the natural environment" (Astley and Van de Ven, 1983). Collective action occurs when organizations form networks capable of acting as a unit to pursue collective goals conducive to the interests of network members.

At the same time, the ambiguity arising from semi-autonomous organziations with frequently incongruent preference orderings; when combined with the relatively fluid participation of network members relative to a variety of issues; suggests that power should be an important phenomenon within a collective action framework. Accordingly, attention focuses on bargaining, negotiation and compromise as tools of partisan mutual adjustment (Lindbloom, 1965) in what are frequently decentralized and incremental decision processes.

Another key focus which naturally arises within this perspective is the question of how order is ultimately preserved or regulated under such collective arrangements. What insures that bargaining and adjustment processes will actually be able to proceed? The theoretical focus here is upon the institutionalization of norms reflecting the shared values of network participants which develop through repeated interactions. As Van de Ven and Astley (1981:448) observe, "this process of norm formation is not usually a rational or random endeavor, but rather emerges as an evolving set of working rules based on reasonable solutions to everyday transactions among conflicting parties". Network organizations comply with such norms voluntarily in adopting a collective orientation to social action.

## ORGANIZATION THEORY AND FOREST MANAGEMENT

It is worthwhile to consider the works of Kaufman, Leman and Culhane in light of

the preceding brief sketch of the major strands of organization theory. This in turn may suggest some potential avenues of research for social scientists with an interest in forestry-related organizations of all types.

**Strategic Choice: Decisions and Power.** Consider first Kaufman's Forest Ranger. The Ranger is the target of a number of administrative cues from higher level management — cues that reflect the goals of those in power. The purpose of the cues is to increase the Ranger's psychological congruence with these goals, a condition which should be reflected in *action* (recall Kaufman's opening line) contributing to goal attainment. Many of these cues have the potential for functioning as *structural* constraints on the Ranger's actions by defining regular patterns of activities and/or social relations to which the Ranger is expected to attend.

All of this occurs *within* the organization. Kaufman comments frequently on the fact that top management "manipulates" Rangers through the use of controls and incentives. In addition, although he is not concerned with the motives of higher level management, he observes that " Where the environment of the Forest Service works against unity, it is neutralized. Where the environment may be actively employed to promote unity, it is exploited. Where the environment helps accidently, it is enjoyed" (p.227). The *structure* of the organization he describes (see Figure 1) is quite consistent with that described within the strategic choice perspective. Kaufman offers ample evidence that Rangers are 'organized and socialized'; he leaves open to question whether such influences are exerted to 'serve the choices and purposes of people in power'. To examine this latter question, a strategic choice perspective would investigate the variety of motives and choice opportunities available to higher level management in 'organizing and socializing' district Rangers; and the ways in which the intra-organiztional environment is constructed to achieve this end. As Pfeffer (1981:160) observes, "there are clearly a range of structural responses available to cope with coordination and control issues faced by organizational managers". A similar approach would be taken regarding management's relations to the external environment. The focus here would be upon managers' perceptual processes of attention, including various biasing effects; and their choices in selecting those environmental elements with whom it would be beneficial for the agency to establish and foster social relations.

Given that the focus of this perspective is on choice (of those in power) , it is not surprising that decision making processes receive much attention within this theoretical orientation. Kaufman's work was strongly influenced by that of March and Simon (1958), who emphasized the significance of organizations' establishing performance programs — i.e., extended decision making procedures — as a means of economizing on information. Van de Ven and Poole (1988) observe that, while assumptions of rationality underlie most strategic choice models, current focus is shifting to more indeterminate processes and their influence on managerial choice. This trend recognizes that decision situations are frequently ambiguous and preference orderings problematic. Indeed, one well-known model pictures certain types of organizations as 'garbage cans' into which pour problems, solutions, participants and choice opportunities (Cohen et al. 1972). What emerges depends on what happens to combine. The focus on probabilistic processes, in contrast to the relative certainty which forms the backdrop of rational decision making perspectives, captures an important dimension of organizational life. Research along these lines will likely remain important, serving as a source of insight for theorists and practitioners alike.

The strategic choice perspective focuses on people in power within the organization — i.e., upper management. Those further down in the hierarchy are in effect considered as part of the internal organizational environment that is enacted and manipulated to fit the purposes of organization leaders. This, of course, would appear to take much of the variety out of life for the district Ranger. But

Kaufman also clearly demonstrated that, based on Rangers' testimony, they were actively choosing to accept most of these constraints and incentives. The Rangers "wish to do as a matter of personal preference the things that happen to be required" ... (thus) ... "they are not consciously 'conforming'; they are merely doing what is right" (Kaufman:198). Leman's warning bears repeating, however, that no matter how strong the Rangers' voluntary committment; it may well begin to break down under the strain of the massive amounts of information and analysis required from the district as part of the current planning and budgeting processes.

If voluntary action of the district Ranger in complying with superiors' controls is matched by a capability of influencing the environment; then it is conceivable that a strategic choice perspective of the organization may be appropriate *at the district level as well.* This is precisely what Culhane examined in his study by testing a viewpoint that was not consistent with strategic choice — i.e., "the core principle of open systems theory .. that an organization's environment determines its behavior" (Culhane:195). As noted earlier, this latter perspective would be supported empirically if policies of Rangers with one type of organization-set were significantly different from those with another. This did not happen. Culhane found that the Ranger apparently *can* influence the environment by maintaining a balanced organization-set, in which those with competing interests 'keep an eye on one other'. The result is that the Ranger's autonomy is enhanced, or at the very least preserved. These results are consistent with resource dependence theory — a strategic choice perspective with somewhat greater emphasis on external constraining forces than 'pure' versions of the theory. In this case, the controls and incentives from above are some of the constraints the Ranger must 'put up with' while still maintaining a fair degree of administrative autonomy. The Ranger also depends on the environment in the sense that constituency interaction and support is politically important to maintaining both bureaucratic power and resource management effectiveness.

Thus a strategic choice perspective at the district level would picture the Ranger as: a) proacting with the environment, despite the presence of certain external constraints; b) acting voluntarily in accepting the intraorganizational constraints and incentives from above (this is not actually a *strategic* choice, but the fact that it is voluntary implies that it does not interfere with the Ranger's exercising such choice in other areas); and c) 'organizing' and 'socializing' subordinates on the district to serve the choices of the person in power — i.e., the Ranger.

An apparent anomoly now arises. If strategic choice focuses on those in power, then it would seem that higher level management would exercise such choice. However, in light of the above, it would appear that strategic choice characterizes both top management and district levels; when such choices should emanate primarily from power centers (i.e., upper management).

The critical concept that may aid in clarifying this situation is that of **meaning.** Top management 'sends down' a communication; their interpretation of that message is that it is to serve as a constraint. The Ranger does not interpret it in this manner and responds willingly. Voluntary action cannot decrease the Ranger's overall capacity for exercising strategic choice. Thus it is through the creation of meaning, derived via the interpersonal meduim of language, that a communication of constraint is transformed into a message consistent with voluntarism. The transformation of the social relation is facilitated through the interpretive act of the district Ranger. This preserves the coherence of a strategic choice perspective across levels of management within the organization. In effect, both Ranger and those at higher managerial levels are subjects who describe, explain and attach meanings to communications and other social practices. The significance of how these descriptions and categorizations serve to 'encode' experience with meaning is receiving increasing emphasis within social science (Rainbow and Sullivan 1987). Though numerous conceptual problems remain, perspectives such as strategic choice which adopt this

approach to social action will undoubtedly remain an important part of organizational analysis.

**Systems and Structures**. Strategic choice thus emphasizes power — the ability to choose and have that choice make a difference — and decision making processes as critical foci for the study of organizations. Nonetheless, even with power and choice opportunities, little will be accomplished without some structure to the activities undertaken. The structuring of such activities within organizations has been the main theoretical emphasis of open systems theory. From the perspective of top management, the district may be envisioned as performing a number of functions within the organization (indeed this is frequently how programs and budgets are organized). District personnel occupy roles within functional subsystems, and both subsystems and roles therein need to be arranged efficiently if the district is to produce outputs consistent with managerial and/or organizational objectives. From this perspective the behavior of the Ranger is viewed as determined from above; with the Ranger reacting to whatever is sent down the managerial pipe. Top management may or may not be choosing strategically. Even if they were, such actions would be examined in terms of their contribution to integration of the system. Moreover, whether or not management's specific purposes are known, the interrelationships among activities being conducted on the district may be studied from the view of how they fit together in producing the kinds and levels of outputs that are produced. With respect to external organizational relations, both Rangers and upper management would be viewed as reacting to impulses from the environment; although the sources and intensities of such stimuli would undoubtedly vary.

One difficulty with this perspective in *social* science arises from the fact that open systems theory deals with the organization as a system of *roles*; when it is people, not roles, who interact. Roles are important in addressing the nature of and relationships among tasks that must be accomplished; but they are essentially abstracted from the actions performed by those who occupy them (Miller, 1978:20). As an element of social structure, a role is a kind of rule that is "recursively implicated" in action (Giddens, 1979:64); A comprehensive social systemic perspective must relate the interrelationships of roles to a more basic question: how do member actions combine to bring about recurrent patterns of social and technical relations (i.e., structure) that lead to the definition and attainment of organizational objectives; and how do these structures in turn influence subsequent actions? In essence this reflects a more general aspect of social reality — the dialectical relationship between action and structure; and understanding this fundamental aspect of human life is one of the major tasks of contemporary social theory (Giddens, 1979). The action-structure dialectic is in fact a key logical basis underlying the voluntarism–determinism axis within the metatheoretical framework for organization theory developed by Van de Ven and Astley (Figure 1). The different orientations therein capture parts of the picture — but the nature and limits of the theoretical linkages have only begun to emerge.

**Natural Selection**. The natural selection perspective would not, at first glance, seem to be a particularly rewarding one for the study of *public* forestry organizations such as the U.S. Forest Service. The problem here is that the forces for 'selecting out' organizations in the public sector are much weaker than those facing their counterparts in the private sector (Kaufman, 1976). Nonetheless, were the time frame expanded to the 'very long run', an evolutionary perspective of the variation, retention and survival of particular organizational forms in the public sector might be envisioned.

On the other hand, a natural selection orientation has obvious relevance to private sector organizations, particularly economic actors. Of particular interest here is the "market failures" framework (Williamson, 1975) as a theory of how the forms of modern corporate organizations and industries emerge and evolve. The theory postulates that when the transactions costs of

acquring inputs from markets become too great, the firm shifts to hierarchies within the organization to provide the inputs in question. The evolution of the multilevel firm is one result. Such a perspective may do much to enrich the understanding of industrial structure and performance within the forestry sector. At the same time, it is important to recognize that the key dynamic operating here — regardless of the specific theoretical focus within this perspective—is the *structural* dominance of an all-encompassing natural and social environment.

**Collective Action: Strategic Interaction.** As noted earlier, Kaufman's study was couched at the micro level of organizational analysis. Culhane looked at certain characteristics of selected populations (i.e., organization-sets) and their effects on a particular focal organization. In doing so, he developed a quantitative model of group influence that was essentially econometric in nature. It may be recalled that economic perspectives are premised on a basic assumption that only individuals can act purposively; and that a population is defined as the aggregate of individuals (or individual organizations) therein.

A collective action perspective rejects this assumption, holding that organizations purposely join to form networks that manifest emergent properties. The focus here centers upon the synthesis of voluntary, normative and political means for use in mobilizing people and resources in a purposive collective effort. Culhane asked Rangers to list all key contacts (i.e., group representatives) who were not a part of their agency; while interest group individuals were asked only to list contacts within the Forest Service. Were this framework extended to include interest group contacts with each other, the entire social network could be modeled for a variety of relations (e.g., exchange of resources, money, information, etc.). Attention could then be directed at how individual organizations, perhaps with opposing interests, come to arrive at social arrangements through which policy matters may be effectively addressed; and the norms through which such arrangements are maintained.

At the same time, the structural effects of a collective action network may be articulated as well. This involves examining the ways in which patterns of network resource and information flows exert a structural influence on the outcome of collective negotiations and bargaining. Moreover, from the perspective of an individual organization, an actor's network position (e.g., central or peripheral)—identified via procedures for analyzing its relations with all other organizations simultaneously (Burt, 1980) — could be viewed in terms of its structural impacts on the likelihood of policy outcomes conducive to furthering its interests. The study of the formation and maintenance of interorganizational networks (Lauman and Knoke, 1987) — within or spanning both public and private sectors — represents an area of research with great potential relevance to the management of forestry-related organizations. It is evident here, moreover, that the dialectical relationship of structure and action operates at the macro level as well. Studies of collective action will be an important tool in bringing this relationship more sharply into focus.

Organization theory can contribute much to an understanding of the social processes through which forest management is initiated and accomplished. This brief sketch, though hardly a thorough description of the field, has outlined some conceptual lenses through which forestry-related organizations may be envisioned. Theory not only serves to stimulate the generation of hypotheses; it also enables one to carry on a conversation. Those participating may not agree on the adequacy of particular frameworks, or even interpret them in the same way. Nonetheless, in the process ideas are fleshed out, terms are clarified, and knowledge given a chance to grow. If this paper has aided in any of the above, it will have served a useful purpose.

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## USING HOMEOWNERS' TREES IN URBAN RESEARCH

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**Abstract**. Interest in studying the urban forest has increased over the past several decades. However, performing research studies in this environment presents some new problems. In forest research, a scientist can generally locate the necessary number of study trees within the ownership of a single individual or organization. This simplifies the process of soliciting permission to utilize the trees. It also reduces experimental design problems since all the trees are under similar managment. This is not the case with urban forest research. Wth the exception of city-owned trees, each potential study tree is owned by a separate individual, a homeowner. This greatly complicates locating trees with similar sites or past management histories. It also increases the difficulty of receiving permission to utilize the trees.

Selecting the study trees requires consideration of many factors; uniformity or age class, past management history and distance from other potential study trees are all possible elements. Receiving permission to use homeowners' trees demands a high degree of empathy. The researcher must understand what motivates people to volunteer their trees and the various tactics used to gain and maintain their cooperation.

Our urban studies of the bronze birch borer will be used to demonstrate methods of designing urban forest studies and soliciting homeowners' cooperation.

## WHAT BIOTECHNOLOGISTS DO, HOW THEY DO IT, AND WHY

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**Abstract**. Biotechnology, in its simplest context, is the technological use of biological agents. However, when one asks the question as to what biotechnologists do, one sees how complex, diverse, and revolutionary this research area is. Just considering plant biotechnology we find studies dealing with cell, tissue, and organ culture; in vitro screening, somaclonal variation, secondary product production; protoplast isolation, culture, and fusion;genetic engineering; gene isolation, gene splicing, and gene engineering; and modification of microorganisms so that they serve valuable roles in agricultural production or waste treatment. With topic areas as broad and diverse as these, it is impossible to generalize as to how all biotechnologists conduct their research. However, since this newly developing field offers forestry researchers unparalleled opportunities for rapid advances, it is appropriate to examine how biotechnology experiments are generally developed and why they are so designed. This presentation will briefly describe the types of research conducted to date and then will speculate as to ways to most efficiently address remaining research needs in forest biotechnology.

# SOME CHARACTERISTICS OF HIGH QUALITY SCIENTIFIC RESEARCH

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**Abstract**. High quality scientific research seems a common goal for scientists. But, based on recent analyses of National Science Foundation grant proposals there is little agreement on what constitutes quality in research . The following characteristics that may help to identify quality research are discussed briefly: scholarship, citation analysis, society needs, answers or questions, degree of quantification, creativity or originality, scientific method, productivity, closure, maturity of science, and paradigm. Characteristics are summarized according to the source of the criterion (internal to the scientific questions or external to the specific scientific questions) and the time perspective in which the research is viewed (short term , e.g., the study is an event; or long term, e.g., the study changes something, the paradigm or the maturity of the science). Each combination of the summaries has an arbiter of quality. Thus, there is no single criterion. However, scientists can not afford to ignore the paradigm.

## INTRODUCTION

Quality in research is a common goal for most scientists. However, there seems little agreement on what research quality is. For example, Cole et al. (1981) found that the fate of particular National Science Foundation grant applications was partly determined by characteristics of the proposal and investigator, and partly by a random element they called "luck of the reviewer draw." One of the goals of this paper is to organize and discuss some of the different characteristics of research that may label it "high quality."

Is there a need to identify and discuss characteristics of research quality? I think so, because quality in scientific research should not be a secret formula that only a few persons are aware of, or that some scientific laboratories have while others do not. The characteristics of research that warrant it being called "high quality" should be public information.

## DESIRABLE QUALITIES OF THE CHARACTERISTICS

Science is a social process. Scientists are human and need reward and gratification just as much as others do, perhaps even more so. In identifying characteristics, we must recognize that merely stating them will cause scientists to react. One reaction, the desired one, of scientists may be to genuinely change methods, approaches, and designs to make their research have the stated characteristics. On the other hand, and again simply stated, scientists may change their research somewhat to make it appear improved, but in fact make no fundamental changes.

Consider, for example, recent efforts to judge research productivity. The criteria have caused scientists to react in an undersirable way. As a scientist's research productivity was publicly suggested to be measured by number of publications in a fixed period of time, scientists responded with a large number of short manuscripts, so-called least publishable units, each just large enough to warrant separate publication (Broad 1981). Productivity appeared to increase, but actually did not. Similarly, as frequency of citation in the literature became a criterion, the frequency of multiple authorships and multiple self-citation became more common. A recent paper in Science had 17 coauthors. A subtle variation used by some scientists who review many manuscripts is to suggest to the journal editor, in anonymous review comments, that the author cite one or more of the reviewer's papers. Combined publication of small units and citation manipulation greatly influence the appearance of productivity, but make no fundamental changes in it.

Each of these characteristics was probably useful in judging productivity until scientists began to change their mode of operation to make themselves appear highly productive.

Any characteristics selected for identifying research quality should reflect the best possible understanding of what constitutes quality and be immune to the reactions of scientists wishing to make their work take on the unwarranted appearance of quality.

## NARROWING THE PROBLEM

Scientific research is the process by which scientific knowledge grows, and is dynamic in its own right. To make my task here more tractable, I will treat only the kinds of scientific research done during what is commonly called "normal science," the paradigm phase (Kuhn 1970), or is less commonly known as "the building and internal criticism phase" (Radnitzky 1973). The characteristics of high quality research in the preparadigm and crisis stages (Kuhn), as well as the pioneering and senility phases (Radnitzky), may be quite different from what I will discuss. Also, I will discuss only research where one wishes to make a statement about reality, the world out there, in contrast to a statement about how to study the world (methodology).

With these limits let me begin by reviewing some characteristics that have been suggested as quality indicators.

## CHARACTERISTICS

**Quality and scholarship**: Perry (1985) tested a hypothesis first suggested by Dillon (1981) that scholarship is reflected in the occurrence of colons in the title of a research paper. Scholarship is defined in terms of "publishability, productivity, complexity of thought, distinction of endeavor, and progress of the enterprise" (Perry 1984). The argument here is that colons are needed to adequately express the complexity of the more scholarly efforts, leading to the term "titular colonicity." Perry analyzed 21,000 papers in ecology from seven "classes" of journals, ranging from the Journal of Theoretical Biology (highest), to dissertations (lowest), and found a definite increase in the frequency of colons in titles from lowest to highest. Of course, the mere mention of the characteristic has made it impossible to test it on future research.

**Quality and citation analysis**: Citation analysis, here limited to frequency of citation, is an increasingly popular evaluation criterion. The logic is sound, at least on the surface. An often cited paper must be a paper of exceptional quality, the argument goes. My reaction is that an often cited paper may be of exceptional quality, but it need not be. To be cited frequently a scientist must be known, publish in widely read journals, be in a well-funded research area, and, ideally, be a member of the inner circle of the scientific community in question. The established scientist has an inherent advantage in any system based on citation analysis. This is expressed as the Mathew effect: "the accruing of greater increments of recognition for particular scientific contributions to scientists of considerable repute and the withholding of such recognition from scientists who have not yet made their mark" (Merton 1968). (See also Serratosa 1984.)

**Quality and society**: Science may be thought to have an inside and an outside. The outside of science is its place in relation to society as a whole, and the latter's needs and expectations. The inside of science is, for example, its method, subject matter, strategies. One might argue that the degree of coincidence between a scientist's research area and the current needs of society help to indicate quality. I will not. Research topics come into and go out of favor as societal needs and funding opportunities change. In my short career as a scientist, I have seen several large research programs come and go: the biome study groups of the International Biological Program, the so-called big bug research programs, to name two. I do not know that any great advances resulted from these programs. Today biotechnology and acid deposition are two highly favored research areas. But, their future seems no different from other short-term research programs

heavily funded from special legislative appropriations. It may be tempting to think that an acid deposition scientist is doing high quality research because the effort has the trappings of a high quality operation—thousands of dollars of research funding, post-docs in the lab, plenty of travel funds, invitations to speak and contribute chapters to books, and so on. Of course, such things do not ensure quality.

**Quality and answers** or **Quality and questions:** We naturally think of research as providing answers to questions. However, sometimes the primary output from research is a well stated question. An old saying is "well-stated is half solved." Mathematician David Hilbert (1862-1943) is famous among mathematicians for his work in several areas of advanced mathematics, but also for posing some 23 unsolved problems that have served as a yardstick of the progress of mathematics for the first part of the 20th century (Kramer 1970). We definitely should not discard well-statedness of questions as potential characteristic of research quality. This is especially true if the poorly funded lone investigator is to have a chance to be fairly judged. Deep thought, the source of incisive questions, may not be an expensive item to support. However, the development of answers in empirical science usually requires some contact with nature — which can be very costly.

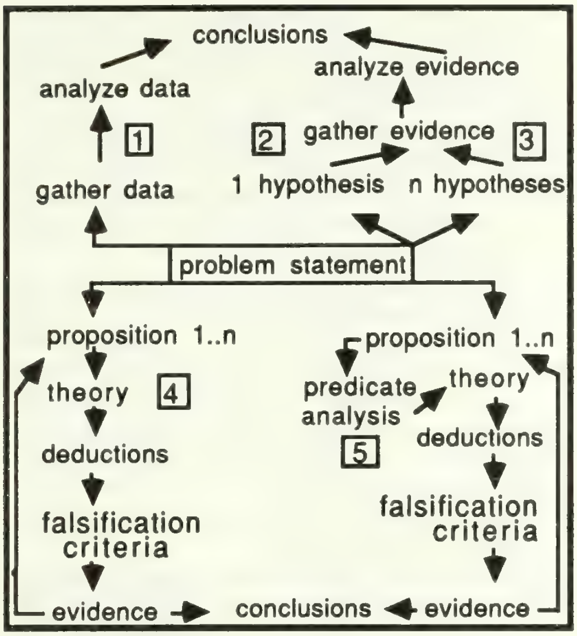
**Quality and quantification**: This is a tempting characteristic. The argument is that scientists in the more mature sciences, such as physics, do higher quality research than scientists in, say, the social sciences, because the concepts of physics are quantified, the propositions are nearly always expressed as mathematical equations, and the theories of physics are expressed as one or more mathematical equations. One time many years ago I tried to represent the degree of maturity in a special branch of ecology (population dynamics) by organizing the representing constructs according to the mathematical methods used in their expression:

algebraic equations
...
differential equations
(ordinary, partial)
...
integro-differential equations
...
integral equations

The trend here is toward an increased capacity of the mathematical construct to represent complexity in the process under study. Nonlinear ordinary differential equations have the potential to represent more complex system behavior than algebraic equations. Likewise, partial differential equations have the potential to represent system behavior in more than just the time dimension commonly used in ordinary differential equations. Integro-differential equations accommodate historical effects. Integral equations are used to express very general over-riding "principles" governing the behavior of systems (Volterra 1959). Degree of quantification is an indicator of quality. However, the more important indicator seems to be a progression, a change, down the scale. Clearly, some scientific disciplines do not have relationships expressed as differential equations. Thus, what signals quality is a change from relationships expressed as algebraic equations to ones expressed as differential equations, in this case of population dynamics.

**Quality and creativity or originality**: This is certainly an appealing characteristic. However, creativity and originality are such vague concepts in their own right that they should not be used in an attempt to clarify "quality," which is itself a vague concept. Another point about creativity is that it may be more important in the crisis period, or the pioneering phase of a scientific tradition, than in the normal science period.

**Quality and scientific method**: Given a question statement, one may attempt to determine the answer by following one of several sets of interrelated steps. I have suggested five different sets (loop numbers) as shown below.



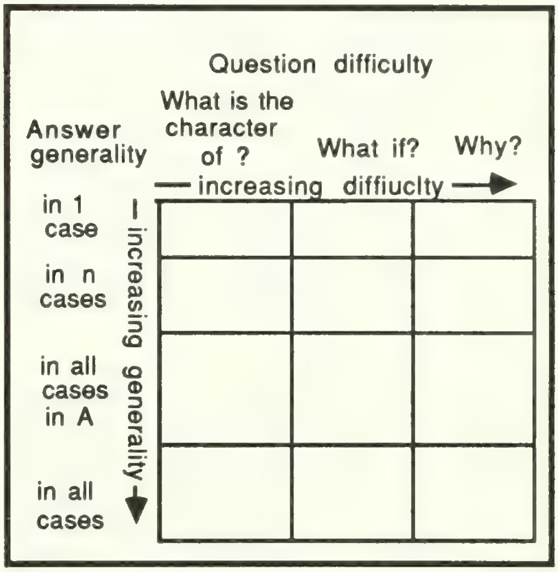

(Source: Leary 1981). Loop 1 is essentially the discovery phase of science. The "conclusion" for loop 1 is one or more hypotheses. In loops 2 and 3 the process begins with at least one hypothesis. Loops 4 and 5 include loops 2 and 3 but have added analyses of the concepts (predicates) involved in the hypotheses (propositions). The rationale for this suggestion is that a scientist who consistently follows loop 5 steps reveals a depth of understanding not evident from, say, one following loop 2 steps. Further, by expressing this understanding, the loop 5 scientist may well advance the science more than others. This characteristic is quite immune to abuse and, if followed, would move scientists in a desirable direction, I think.

Bunnett (1984) argues that quality in research shares some of the same characteristics as quality in manufacturing:

reliability — experience shows that the results can be repeated or confirmed,
design — an investigation is to be admired if it achieves a major objective by means of a few adroit experiments, or provides several kinds of important information simultaneously,
workmanship — care is taken to verify observations made.

Special to research, however, is what he calls "intellectual analysis of the work" — a high quality study evaluates critically the observations made, indicates their limitations and features deemed unchallengeable, and points out the significance of findings (Bunnett 1984).

**Quality and productivity**: Recently I proposed a framework for assessing a scientist's research productivity (Leary 1985). It consists of combinations of general classes of question difficulty and answer generality.




Answers to easy questions that apply to few objects are considered to constitute less productivity than answers to difficult questions that apply to all known or possible objects of a class. Productivity of a scientist cannot be judged entirely by the two coordinate axes because some sciences do not have universal explanations, or anything approaching them. There is more likely a "frontier" of knowledge for each problem area in each discipline that may have a lower-left to to upper-right slant. Productivity, then, must be judged by how close the scientist's work is to the frontier. Is the scientist pushing back the frontier of knowledge, or filling holes left by the pioneers? To me this framework helps to clarify the difference between quality and quantity of a scientist's research productivity. It also shows clearly that research

productivity is relative to the scientist and to the scientific discipline.

**Quality and closure:** In science, as opposed to mystery writing, we can never say for sure that "the case is closed." However, we would like to be able to say on occasion, "now we know this." Somehow, doing high quality research means settling the issue once and for all (as far as can be determined with present knowledge). The alternative is frequently reopened cases in light of "new" evidence, a form of running in place. The measure by which we "close" cases is the capacity we have to detect alternative hypotheses (if they were true) when conducting our experimental studies. If we know we have a very good probability of detecting the alternative and we fail to do so, this lends a great deal of confidence in the original hypothesis. This measure is the power of statistical tests. Power is more than reproducibility. In fact, the latter seems of marginal value in demarcating science from nonscience. How many reproductions are sufficient?

**Quality and maturity of a science**: Philosophers and scientists have assembled criteria that, they argue, indicate the maturity of a science. Roughly speaking, a science, or a special area within a science, is more mature if it has breadth (it covers the range of phenomena studied in the science), depth (it makes use of more than one level of organization in its constructs), and cogency (forcible, clear, or incisive presentation) (Bunge 1968). A discussion of characteristics of more mature sciences is relevant because it may be desirable for a scientist's career (ontogeny) to parallel (recapitulate) the generic change that has matured a discipline (phylogeny).

Bunge (1968) lists changes one should expect as a science matures:

empirical concepts should give way to transempirical concepts.

> Advanced sciences deal with concepts that refer to things and properties of things that are not observable.

information packages should give way to hypotheses.

> Curve fitting summaries of data are replaced by conjectured change equations that, when integrated, produce the observations.

black box representations give way to representations with a mechanism.

> In mature sciences mechanisms underlying patterns are known or strongly conjectured.

subsumptive explanation yields to interpretative explanations.

> Mature sciences not only have covering laws by which to explain events, but they have relations based on more than one level of organization (either the same level or both higher or lower).

unorganized theories are converted to axiomatized theories.

> Mature sciences are better organized than immature ones. Assumptions are well spelled out. Concepts and propositions are identified and expressed appropriately. Theorems and corollaries are deduced.

Practically speaking, the concepts in more mature sciences are:

relation and quantitative concepts instead of class concepts,
removed from Margenau's plane of perception,
of higher degree and order.

The propositions of more mature sciences:

are law-like relations,
are often expressed as implicit functions,
have few, if any, unknown numerical constants in their mathematical equations,
are expressed using higher level quantitative mathematical equations.

The theories of more mature sciences:

answer Why questions,
are better organized than those of less mature sciences,
may be axiomatized.

The research methods of more mature sciences involves:

forming at least one hypothesis and using alternatives to confirmation,
identifying the factual predicates in the propositions (hypotheses), and analyzing them.

**Quality and the paradigm**: The concept of a paradigm has played a large role in science since its use by Kuhn (1970) in describing scientific revolutions. Here, I consider a paradigm to be, roughly speaking, a set of shared beliefs about how some aspect of nature operates. During periods of what Kuhn calls "normal science," the paradigm functions somewhat as an arbiter of research quality. Studies that build, enhance, or strengthen the paradigm will naturally be judged higher in quality than those that do otherwise.

Paradigms are not static, but they seem to change more slowly than one might expect. To some degree paradigms may tend to be fashions, especially in areas of methodology research. For example, Hoch (1985) reviewed the primary tools used in the analysis and discourse sections of articles appearing in two agricultural economics journals in 1950, 1966, and 1983. The primary tools shifted radically from those based on English, descriptive statistics, economic geometry, and economic algebra and calculus, (used 28 times in 1950, 23 times in 1966, and 6 times in 1983) to those that use econometric models, programming and simulation models, other econometric models and mathematical economics (0,11,26 for the respective years). Thus, the analytical paradigm shifted considerably in the 33-year period. Clearly, a paper submitted to either journal in 1983 with descriptive statistics (farm budgets, distribution of variables, index numbers, etc. Hoch 1985) as the primary analytical tool would have been rated low in quality.

## ORGANIZING THE CHARACTERISTICS

Listed below are the characteristic of research that seem to bear on quality.
scholarship
citation analysis
society
answers or questions
quantification
creativity or originality
scientific method
productivity
closure
maturity of science
paradigm

Most characteristics fall into two general categories. One category has to do with the temporal view behind the characteristic. Are we looking at research in the very short term, as an event or product such as a scientific manuscript, or in the much longer term, as a process, where something is being changed? For example, one tests different research methodologies on a different time scale than one accomplishes the maturing of a science.

The other category deals with the source of the criterion. There are two general categories of sources, one internal to the research area in question, the other external to the immediate research area.

The framework formed by these two organizing, supra-characteristics is as follows:

| | | Source of criteria | |
|---|---|---|---|
| | | internal to research | external to research |
| | | - - criteria -- | |
| View of research | product | methods closure | citation frequency |
| | process | paradigm | maturity of a science |

The framework suggests that in the short term methodology, closure, and citation frequency may be appropriate measures of research quality. In the longer term support for the paradigm and contribution to the maturing of the science seem important measures of research quality. Based on internal criteria, methodology, closure, and paradigm seem to fit together; for external criteria, citation frequency and maturation of the science seem to be similar.

If one cell in the grid is more crucial that others, it is most likely the internal — process cell where I placed paradigm. Recall, we are speaking of the period of normal science, where the paradigm is for the most part respected and revered. A piece of research that runs counter to

the paradigm may have difficulty making it into print. However, paradigms are the fashion part of science. I suspect that a study of the history of a bit of science would show that some paradigms actually set back the maturation of that bit of science. Yet, in the shorter term, these very ideas probably weeded out what was acceptable for publication.

The two off-diagonal cells reflect the fact that what is judged high quality research is just as much a social process as science itself. The two main diagonal elements reflect that one cannot judge what constitutes research quality without digging into the questions and methods themselves.

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# RESEARCH REWARDS IN THE USDA FOREST SERVICE AND THEIR ROLE IN THE SCIENCE VS. TECHNOLOGY TRANSFER DILEMMA

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**Abstract**. Research rewards are discussed from a systems point of view. Three classes of rewards are described: internal, informal, and formal. Internal rewards originate from within the scientist. Attributes, such as creativity, lead to rewards such as a sense of fulfillment from developing new concepts. The scientific environment can either reinforce or weaken these rewards.

Informal rewards, such as research freedom, ego satisfaction, peer recognition, and user acceptance stem from the scientific environment. A mismatch between the goals of a research organization (publish) and an individual's reward value system (doesn't like to write) leads to difficulties (perish).

Formal (material) rewards are provided by the research organization. They come in three forms: research budgets, salary, and employment. The Forest Service formal reward system is oriented to two factors: rate of production (including administrative tasks) and the quality of science. The reward system is not well-suited to technology transfer; hence it receives less emphasis than other activities.

A scientist's time will be filled in proportion to his/her individual ranking of various rewards, constrained by organizational requirements. Thus, a reward system can enhance or inhibit the attainment of organizational goals. In the latter case, research managers may be unaware of the impact. Although evaluating and rewarding research is a difficult challenge, everyone benefits from developing better systems.

The goal of the research reward system in the USDA Forest Service is to reward and encourage scientific productivity. To quote Paul Waggoner (1983), in "evaluating basic and [applied] research, the director . . . . marvels at scientists who produce both, appreciates those who produce either, and worries about those who produce neither." Rewards offered by the Forest Service include those common to most institutions: promotions, certificates of merit, cash awards, and similar honoraria. The institutional reward system is part of a larger reward structure that motivates scientists to tackle difficult problems, generate new information, and publish their findings. This larger reward system involves, in addition to the rewards cited above, the characteristics of individual scientists and the environment in which the scientists work. The interplay of these components can have a pronounced effect, not only on scientific productivity, but also on our ability as a Government agency to respond to the needs of the people we serve.

The needs of various user groups have traditionally been addressed through the technology transfer efforts of scientists. Whether through "how to" pamphlets, workshops, or videotapes, scientists have tried to pass on knowledge generated from their research to land managers in a usable format. But the rewards for these activities are different from those for scientific productivity. Hence the dilemma: How does a scientist balance these two important activities — science and technology transfer?

To explore the role of research rewards in the science vs. technology transfer dilemma, we present our view of the research reward system in the Forest Service. We then discuss the dilemma posed by the system and describe its impact on our research and technology transfer activities. We conclude with suggestions that may enable the Forest Service to better fulfill its commitment to solving land management problems and effectively applying research results

while maintaining (if not improving) scientific productivity.

## THE RESEARCH REWARD SYSTEM

To better understand the research reward system and how it functions, we identified 16 rewards and grouped them into three classes: internal, informal, and formal. We define internal rewards as self-generated psychological benefits that scientists derive from their work. These rewards are an outgrowth of a scientist's intrinsic nature and quest for knowledge as well as a reflection of his or her unique personality, values, perceptions, and skills. Informal rewards, on the other hand, are generally intangible and, in some cases, psychological benefits that scientists receive from the environment in which they work and from the response of others to their research. Finally, formal rewards, perhaps the most familiar, are tangible benefits that scientists receive from the research organization and from their clientele. Because the value of a reward is linked to an individual's perception, each scientist responds differently to each reward. Progressive research managers recognize this and tailor the reward system under their control to encourage each scientist. This requires an understanding of the types and sources of rewards as well as their impact on individual scientists.

### Internal Rewards

Successful scientists possess characteristics that, when exercised through research, can yield internal rewards (Table 1). Perhaps foremost of these characteristics is curiosity; scientists often want to know why things happen or how they work. Their reward is intellectual satisfaction stemming from satisfying their curiosity and taking a step closer to the truth.

Scientists can also be creative. Not content to repeat or extend someone else's research, they develop new hypotheses and theories through which a discipline is advanced by a step or by a leap. Creative scientists derive fulfillment from developing new ideas, testing them, and demonstrating their efficacy.

Table 1. Qualities and skills of scientists and associated internal rewards.

| Qualities and skills of scientists | Internal rewards |
|---|---|
| Curiosity | Intellectual satisfaction |
| Creativity | Fullfillment |
| Research skills | Pride in workmanship |
| Persistence | Sense of acheivement |
| Objectivity<br>Skepticism | Confidence<br>Self-assurance |

Personal growth

Long-term scientific contributions

Another characteristic of many scientists is persistence. More often than not, a brilliant concept doesn't work the first time that it's tried. A scientist must have self-confidence to persevere despite initial failures. A reward for persistence is a sense of achievement that accompanies any effort in which obstacles have been overcome. There is a corollary to persistence—objectivity. It's a key ability to recognize that evidence is overwhelming a hypothesis and to change direction accordingly. This is what Huxley (1966) called, "The great tragedy of science . . . the slaying of a beautiful hypothesis by a series of ugly facts." Objectivity leads to confidence in the correctness of a solution and in an ability to do "good" science.

Most scientists are also skeptical, constantly asking, "Is it really so?" As James Horsfall (1983) said, "Scientists who accept things as they are rarely set up new hypotheses to test." Skepticism often drives scientists, rarely satisfied with an answer, to generate new questions and pursue research to answer

them. A reward for well-founded skepticism is self-assurance. It comes from producing significant research results and having the potential to advance a discipline, in defiance of conventional wisdom.

Finally, scientists are skilled at research activities such as planning studies, making observations, and analyzing data. They are concerned with details — knowing that one small mistake can ruin a study. Thus, many scientists take justifiable pride in the workmanship of a well-designed and well-executed study.

These examples illustrate some internal rewards stemming from a scientist's intrinsic characteristics. For brevity, we have linked only one reward to each characteristic. It should be clear, however, that each characteristic can lead to many different rewards, according to the value system of each scientist. When integrated, these rewards lead to personal growth stemming from the knowledge that one has made a substantial contribution to a discipline and established a foundation for future research.

**Informal Rewards**

Although we often think of the research organization as a source of formal rewards, it also provides informal rewards such as testimonial letters or public praise for a job well done. Informal rewards are generally intangible and sometimes psychological; an essential feature is their external source (Table 2).

Table 2. The relations between external sources, informal rewards, and internal rewards. Informal rewards can be transformed to internal rewards, providing additional incentives to the scientist.

| External sources of rewards | Informal rewards | Internal rewards |
|---|---|---|
| Research organization | Praise | Pleasure |
| | Research freedom (task) | Sense of recognition |
| | Research freedom (time) | Sense of importance |
| Land managers | Application | Sense of accomplishment |
| Peers | Recognition and respect | Pride |
| Publication record | Publications | Self-esteem |

Sources include the research organization or environment in which scientists work, their clientele (land managers) and peers, and, finally, their publication record (fig. 1).

One important informal organizational reward is research freedom. As Sterling Hendricks (1983) stated, "Freedom to inquire into the nature of things is a rewarding privilege granted to a few by a permissive society." In the Forest Service, for example, we have "pioneering projects" with fewer administrative constraints than other research projects. These are headed by

outstanding scientists, working on the cutting edge of science, who have proven their ability. Such scientists know that they are recognized for being capable of excellent work and judgment.

Freedom also comes in the form of time to do research. Enlightened research managers view their task as removing administrative obstacles to research. This allows scientists more time to conduct research, thereby enhancing scientific productivity. In such instances, scientists sense that their work is important to the organization or the discipline. If administrative rules hinder research, scientists sometimes respond by diverting energy to overcoming the rules, adopting an organization's standard of average performance, or, ultimately, leaving the organization for a less restrictive atmosphere. At the least, creativity cannot flourish in an atmosphere of frustration, and without creativity, there is little meaningful research.

Land managers are also part of the informal reward system. Scientists feel a sense of accomplishment when they see their ideas put into practice. Making things happen, changing the way things are done, and making tasks a little easier can be very satisfying.

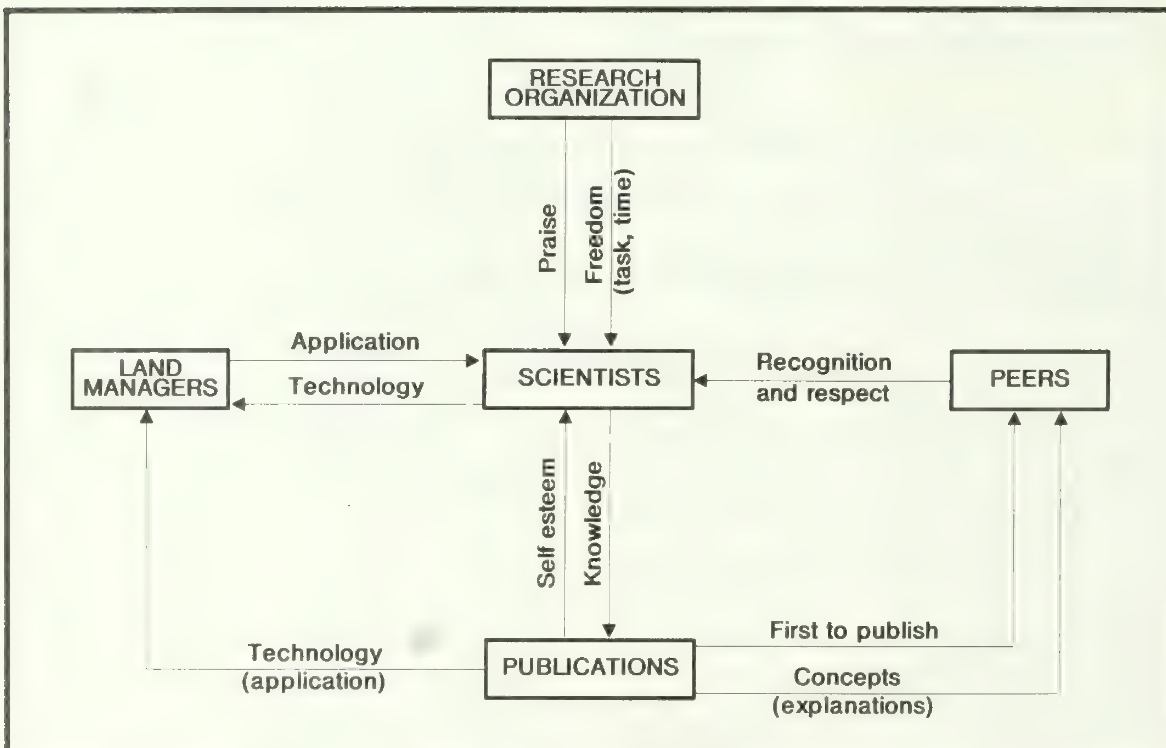


Figure 1. Interactions between scientists and external sources of informal rewards.

Because other scientists judge the value of research, peer recognition and respect are also important informal rewards. The primary route for peer recognition is through publications. The highest form of flattery to some scientists is to be told by their peers that their research was well done and that it produced concepts and explanations that advanced the state of the art. Further, science is competitive. Journals list the date on which a manuscript was received, so that if two scientists complete similar research at about the same time, publishing delays won't affect who gets credit for being first. As with any competitive endeavor, scientists can feel the "thrill of victory" associated with winning. Perhaps the ultimate peer recognition is a paradigm that bears your name in the literature.

Publications are the tangible output of science. They tell land managers how to apply research; they allow peers to evaluate research; and, of course, publications are what research managers count as a measure of productivity. But publications are also an informal reward in and of themselves. Seeing that definitive article in print with one's name on it can boost one's self-esteem. Scientists who value this reward will do well in most research organizations. Conversely, scientists for whom writing is difficult or who are little motivated by this reward, will have problems. Understanding the importance of internal and informal rewards is essential to managing a creative research organization. Many scientists are often driven by what might be called the "joy of research." Management neglect of internal and informal rewards runs the risk of evolving a thoroughly average organization.

**Formal Rewards**

Here we limit the discussion to the research organization most familiar to us. There are four formal rewards that the Forest Service provides to its scientists: salary, awards, a research budget, and employment (fig. 2). All but the highest salaries are determined by the Experiment Station. A scientist's salary is influenced by two factors — productivity and science. Annual performance appraisals are a key determinant of incremental (within-grade and merit) salary increases. These appraisals focus on the number and types of research tasks accomplished, including publications, as well as on timely and accurate completion of administrative reports and management functions. Although scientists are sometimes bothered by publication counting, the Forest Service merely reflects science as a whole. For example, Keith Thomson (1984) comments on the proliferation of trivial papers published in trivial journals, "But 'less is more' may be hard to attain. . . . Publish or perish is deeply embedded in the subculture of science (and God forbid that we should have to find some more valid criterion in order to judge promotions)." By default, administrators are doing, as best they can, what science has been unable to do for itself.

In the Forest Service, a scientist's grade is evaluated every 3 years by a Research Grade Evaluation and Advisory Panel. For a scientist motivated by material rewards, the panel system is very important. Panel members evaluate the scientist's research assignment, supervision received, research originality, and scientific contributions. Based on these four factors, they recommend promotion, retention in grade, or demotion. Although the first three factors are important, scientific contributions constitute 40% of the total score. In essence, a good publication record is generally sufficient for a good panel rating, whereas a weak publication record has to be strongly bolstered by other contributions to obtain a high rating. High ratings result in an essential recommendation for promotion and a higher salary.

Annual appraisals and panel evaluations focus on different attributes of the research process. Scientists must be attuned to the production/science dichotomy and balance their activities to perform well with respect to both systems. Station management must also balance the evaluation process, however, and recognize that production-oriented criteria are ill-suited to innovationand creativity (with their attendant risk of failure).

Although primarily determined by the Experiment Station, awards are granted at all organizational levels. Awards, whether medals, certificates, cash, grants, or some combination thereof, are presented to scientists who have produced research of outstanding quality and/or originality. Such awards publicly recognize scientists for their efforts and creativity as well as enhance career opportunities, and sometimes financial standing.

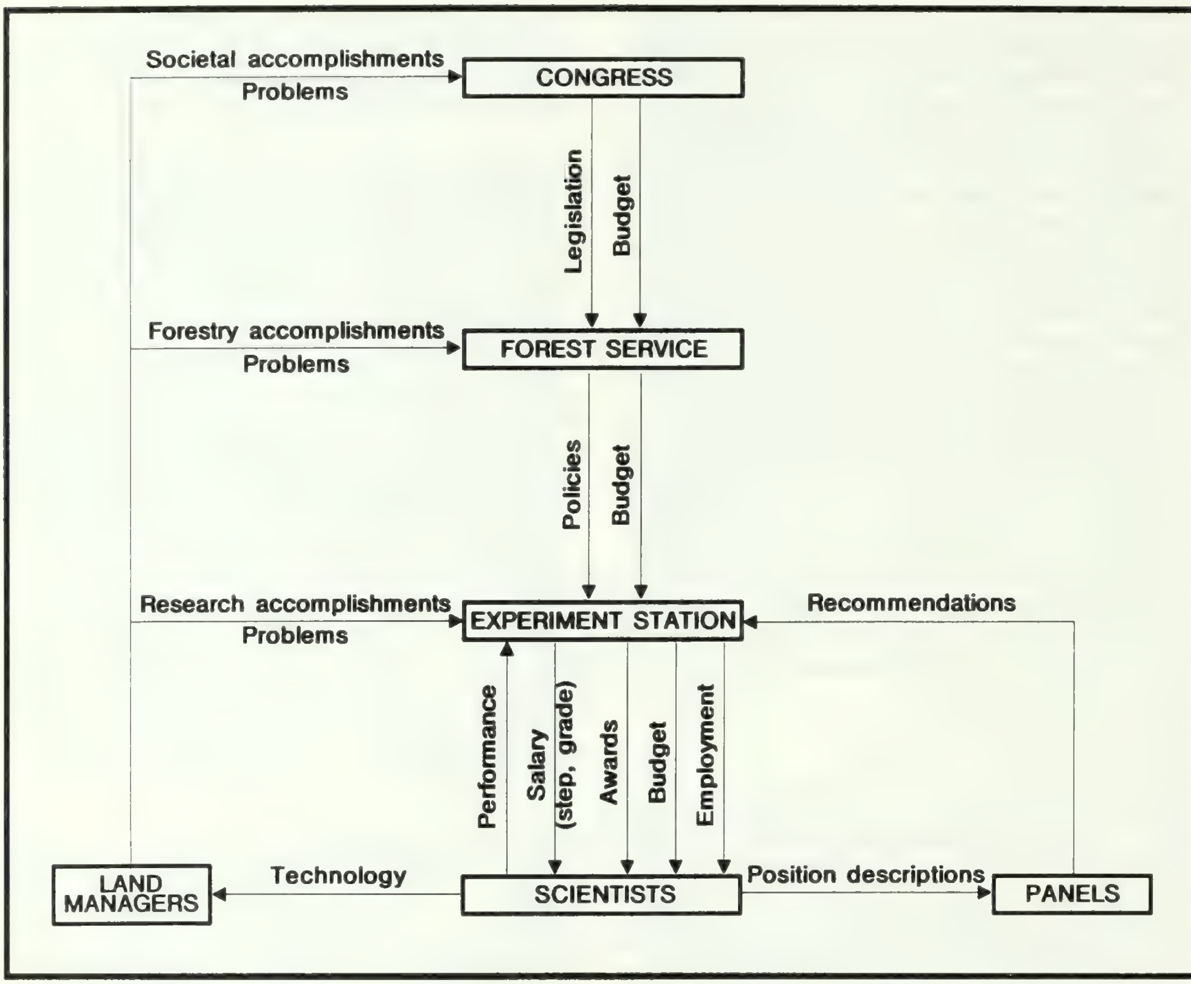


Figure 2. The formal reward system in the USDA Forest Service.

The research budget pays for facilities, equipment, and support personnel, without which scientists are severely handicapped. The research budget is also linked to freedom. There is little point in granting freedom to "seek the truth" but providing insufficient funds to do so. An innovative scientist, conducting world-class research, will not tolerate provincial-class funding for long. To many scientists, quality research facilities, adequate equipment, and sufficient support personnel are as important (sometimes more so) as salary increases.

The research budget is also intimately linked with the last formal reward — continued gainful employment. This is both the ultimate control for research management and the ultimate motivator for many scientists. As specialists, scientists may have limited employment opportunities outside of the research organization. Alternatively, having invested much of one's professional career in an organization makes separation difficult. Many scientists go to great lengths to avoid such a prospect. An important subset of the employment reward is the ability to choose one's location or remain in place after establishing roots.

Unlike most rewards, employment is all or nothing; it can not be applied in increments. Nor are its positive and negative impacts evenly balanced. Starting at neutral, lack of worry is necessary to the creative process. Conversely, varying degrees of concern ranging from the general malaise of "uncertain times," through apprehension caused by seeing associates uprooted, to the threat (real or perceived) of imminent personal

relocation or removal, result in negative impacts on scientific productivity, ranging from slow down to shut down. Management insensitivity on this issue can lead to much wider ranging, longer lasting, and greater negative impacts on research programs than would be expected, based on the magnitude of the original action.

Although the Station has some flexibility in allocating resources, research budgets and decisions to start, move, or terminate research generally originate at higher levels. Land managers play a key role in such decisions, although they exert their influence by circuitous and not always recognizable paths. We must, therefore, view the research environment in a broader context (fig. 2). The interaction of land managers at the Station level focuses on the technical aspects of regional research accomplishments and problems. Competition for resources is within research functions (e.g. fire). Scientists generally relate to this level best.

The next higher levels are concerned with the Forest Service as a whole. Research is evaluated not only in a technical sense, but also in terms of its priority relative to current Forest Service needs, its relevance to the Forest Service mission, and, ultimately, its responsiveness to congressional mandates. Individual projects are subsumed within functions. Competition for resources is first between research functions and then between research and forest management. National priorities may supersede regionally important needs. The interaction of land managers at this level is in terms of accomplishments and problems related to forest management and policy, with research viewed as a supporting function (fig. 2).

Support from land managers for research is especially important when budgets are cut significantly. Management support (or lack of it) for a particular research program can be a critical factor in deciding where cuts must be made. After decisions to cut research programs are announced, it is generally too late to reverse them. Thus, land managers must not only support research, but do so before decisions are made, and their support must be known to the decision makers. Therefore, continued program support requires that scientists 1) conduct relevant research, 2) communicate with land managers, and 3) insure that the existence of management support is recognized throughout the organization. Forest Service scientists not in tune with higher level concerns risk unpleasant surprises during their careers.

At the highest level, research becomes an instrument of public policy—a perspective far removed from that of the scientist. Forestry issues compete with national defense, trade deficits, and unemployment for public attention and, ultimately, legislative attention. Although most government scientists conscientiously serve the public good, there are many public goods, each of which is important to some constituency. Scientists who retreat into the security of their disciplines and make no effort to package their research results into something useful to their clientele, do so at some peril. In the words of Norman Borlaug (1983), "Our research must be good but it must be good for something."

## THE SCIENCE VS. TECHNOLOGY TRANSFER DILEMA

The necessity of producing and communicating results that benefit our constituents, is a key dilemma facing Forest Service researchers. They are confronted with the conflicting demands of a research organization that, on one hand, requires and rewards scientific productivity while, on the other, advocates technology transfer for which it offers limited incentives or rewards. Likewise, scientists, who respond to rewards from land managers for technology transfer activities (e.g., application of research results) must somehow balance these rewards with their associated costs —lower scientific productivity, less time to conduct research, and, ultimately, forgone rewards for research productivity.

To describe this dilemma, we begin by defining technology transfer and to

expand the discussions of why and how Forest Service researchers do it. Technology transfer and application have been defined by Philpot (1985) as the implementation and use of research results and development efforts. Krugman and Creighton (1985) view it as the "adaptation of existing knowledge or technology to serve a new purpose, or its adoption and use by a new group of people. . .This, and related meanings, are the foundation for most of the Federal technology transfer effort. Technology transfer programs tend to be built around the idea of sharing the knowledge or resources for the benefit of the total population."

Along the same lines, Essoglau (1985) notes, "In the public sector . . . technology transfer occurs, at least in theory, when the 'public good' warrants it. . . . Public servants are expected to engage in activity promoting technology transfer because it is presumed to be in the public's interest. It is their legal duty to do so because their technology has been generated with public funds." This has not always been the case, at least in the Forest Service. According to Philpot (1985), "Forest Research historically considered itself a research organization with little or no responsibility for development and application. Considerable change has occurred in the past 20 years and a strong commitment to problem solving and user assistance has been established."

In response to this commitment, researchers often translate the scientific content, style, and format of journal publications into simplified descriptions of how to apply research results. Once these publications are disseminated, managers may be able to extract useful information from them. Scientists have also taken another route to technology transfer—presentations at meetings, conferences, and workshops geared specifically to managers. If a meeting has proceedings, so much the better, because the material is then available to more people than those attending the meeting. Finally, scientists participate in a wide range of technology transfer activities such as consulting and developing training materials and prescriptive guidelines.

Solving practical problems and assisting clientele would seem to be a top priority in most forestry research groups (Wagar 1987). But, in spite of the Forest Service's commitment to technology transfer and scientists' efforts to conduct it, Wagar (1987) concludes that "our reward systems, limited budgets, and perhaps longing for respectability all seem to shift our priorities and energies toward being scientific." And, he notes, "The reward systems of most forestry researchers push us primarily toward publishing, preferably in scientific journals, and away from the hands-on development, testing, and tinkering often needed to make results useful."

One reason for this is the Forest Service emphasis on publications. Historically, according to Philpot (1985), the primary product of research has been and still is "published, peer-reviewed information and knowledge. Publication, the end product of the scientific method for centuries, documents the research so that any competent scientist can repeat the work and duplicate the results. This documentation usually falls far short of providing sufficient information to transfer the knowledge to a practitioner for use in solving a problem." However, as we noted earlier, it can result in numerous internal, informal, and formal rewards for scientists. It also provides the Experiment Stations with tangible, measurable results of their efforts — hence, the heavy emphasis given to numbers and types of publications.

To some degree, this emphasis can hinder a scientist's performance (and consequent rewards) as well as interfere with the very technology transfer that the Station advocates. For example, responding to Station publication pressure, good scientists produce more publications. But, time spent writing superfluous manuscripts is time away from research. Many scientists publish predominantly in journals because such publications carry more prestige for panel evaluations. Unfortunately, land managers are unlikely to see the information, and if they do, it will be written

in the language of science, a language sometimes difficult to comprehend. Scientists may also prefer to attend meetings with proceedings rather than without, as the former include a "counter." Finally, creativity and inventiveness both involve a risk of failure—an unacceptable risk if each study must result in one or more publications. The end product of excess emphasis on numbers of publications may be mediocrity, lesser publication significance, fewer real contributions to knowledge, and, of course, fewer rewards for doing quality science.

Another reward system pressure towards publishing and away from technology transfer is the Forest Service panel system. As indicated earlier, scientists are evaluated by scientific peers using components of the scientific method, impact on future research, scientific and professional reputation, and publication quality and quantity (Philpot 1985). As of this writing, the panel process is evolving toward increased consideration of and credit for technology transfer activities. Many technology transfer subheadings have been added as well as references throughout the position description. The evaluation guide, however, remains science oriented. It is unclear how panels will respond to the new dilemma of evaluating revised position descriptions using unmodified guidelines. Although the evolutionary outcome is not yet forseeable, just starting such a process is a significant step in dealing with the science versus technology dilemma.

Given the historical precedent to publish, Station pressures, lack of incentives to do otherwise, and the panel system's bases for evaluation, it is not at all surprising that scientists opt to conduct research instead of technology transfer. Therein lies most of their rewards whether internal, informal, or formal.

## RESOLVING THE DILEMA

Are there possible solutions to the science versus technology transfer dilemma? An obvious approach would be to change the reward system to encourage communication between scientists and their clients and, as Essoglou (1985) notes, to "reward problem solving directed to modifying and adapting technology . . . at least as much as that connected with creating or inventing a technological innovation." It is not only in the practitioner's interest to do so but in the scientist's as well for, without the needs and support of land managers, Forest Service research has no purpose. It is, therefore, in our best interest to decrease the gap between researchers and managers. According to Krugman and Creighton (1985), senior research managers must bridge the gaps between technology generators and users with incentives. Such incentives will not only encourage scientists to reach beyond traditional assignments, thereby increasing the public's return on their investments (Wagar 1987), but also to seek active participation by users in their research and development (Krugman and Creighton 1985).

In contrast, changing the reward system to encompass technology transfer assumes that this is a desirable activity for scientists. Another view, espoused by Philpot (1985), asserts that, rather than changing the current research reward system, the research organization itself should change. The problem, he contends, is that Forest Service Research "has not made the appropriate distinctions between research and development in its organizational structure, administrative procedures, accountability, funding, and user interfaces." Because the need for development (which he defines as the process of combining, modifying, and integrating existing and new knowledge from research, experience, engineering laws, and judgments into a product ready to implement) has not been identified within the Forest Service, no appropriate organization exists to accomplish it. Instead, researchers do it as part of their technology transfer, clients do it, or no one does it. Consequently, this has both diluted the research effort and inhibited effective application (Philpot 1985).

These and related problems, including the isolation of user assistance and extension functions primarily in State and Private Forestry, could be resolved

if, as Philpot (1985) suggests, the Forest Service established a Research and Development organization that included research, development, application, and extension responsibilities in one branch. Under such an organization, scientists in the Research Division would be responsible strictly for research, while the Development Division, relying on the expertise of staff in an in-house professional pool for assistance, would deal directly with land managers and be responsible for training users and for testing, evaluating, and applying its products. Scientists would no longer be confronted with the conflicting demands of a research organization that requires and rewards scientific productivity but not technology transfer, even though it advocates the latter and delegates the responsibility for it to the scientists.

Until these or other solutions become reality, however, the Forest Service research reward system will remain as it is—a complex interplay of rewards not only from within scientists, but also from external sources such as publications, peers, the research organization, and, of course, land managers. Realizing the dilemmas created by such a system, we, as scientists, face a challenge: to honor two masters—science and its ultimate beneficiary, the people whom we serve. Knowing the benefits of serving each, we must choose how best to serve both, fully recognizing the costs as well as the rewards of our decision.

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# Risk Analysis Proposed for Evaluating Impacts of Scientific Research on Economic Decision Making

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**Abstract**. Risk analysis is proposed as a quantitative method for evaluating impacts of scientific research results on economic decision-making criteria. Scientific research is assumed to produce new scientific knowledge, including new data, theory, and discovery. Such outputs have two kinds of impacts that are assumed to be important in rational economic decision making: change in the possible modes of economic activity and greater certainty about economic outcomes of selected activities or events. These two impacts are described quantitatively as changes in probability density functions, as shifts in the range and likelihood for possible outcomes of events and related economic activities. Risk analysis based on Monte Carlo simulation provides a quantitative method for estimating how decision-making criteria are affected by such changes in the probability distribution of possible outcomes. Conceptual examples are drawn from the area of forestry research and forestry decision making.

## INTRODUCTION

Economic analysis usually begins with an assumption that individuals make economic decisions based on rational criteria such as maximization of consumer utility or producer profits. As a whole, economic behavior may not be entirely rational, depending on whether one adopts a belief that decisions result in a rational allocation of resources or a belief that such decisions simply result in an irrational arrangement among individuals with conflicting goals. Nevertheless, when economic decision making is supported by rational evaluation of possible outcomes, quantitative and rational criteria are often employed. Criteria such as the anticipated levels of profits, costs, product performance, or returns on investment are commonly used to support economic decision making by both producers and consumers.

The general area of evaluating scientific research has been a problem for economists. It is impossible for anyone to evaluate specifically all possible economic impacts of research, simply because it is impossible to anticipate all future applications of scientific knowledge. As such, scientific research will intrinsically have future economic impacts that presently cannot be fully appreciated. Thus, any evaluation of scientific research is limited.

This paper is not concerned with how to evaluate scientific research in general but simply with how to evaluate current and foreseeable impacts of scientific research on economic decision-making criteria. According to conventional economic theory, economic decision making is the vehicle through which economic impacts of research are thought to be arranged.

## SCIENTIFIC RESEARCH AND ECONOMIC DECISION MAKING

When economists have attempted to evaluate economic impacts of scientific research, they have typically evaluated impacts of research on production through technological advances that are traced as "spinoffs" to the scientific research (e.g., see Bengston, 1985). As such, economists have tended to highlight noteworthy scientific discoveries and technological innovations and the associated economic impact of modal change in economic behavior. The outputs of scientific discovery and technological innovation certainly allow for selection of new modes of activity in economic decision making. However, scientific research produces outputs other than discovery and innovation, including new data and more precise theory, much of which serves in economic decision making to reduce uncertainty about outcomes of economic activities or events.

As such, outputs of scientific research are applied in economic decision making not only toward selecting new modes of economic activity, but also toward reducing uncertainty about consequences of economic activities. This paper proposes a method for evaluating impacts of scientific research on economic decision-making criteria, considering together the research impacts of reduced uncertainty and availability of new modes of economic activity. The method is based on a simulation approach to economic analysis known as risk analysis.

Risk analysis is a technique used for simulating economic outcomes of events and activities in cases where there is some uncertainty about the possible outcomes (Hertz and Thomas, 1983). In such cases, the quantitative knowledge that does exist about possible outcomes is summarized in probability density functions. Monte Carlo simulation is then used to obtain a large random sample of possible outcomes from the known distribution of possible outcomes. The sample is used to simulate a probability distribution of possible economic consequences. Simulation is used to show the anticipated probability distribution for economic decision-making criteria, such as the probability of achieving certain returns on an investment or the range and likelihood for total costs of a project. Results can be used to show the likelihood of economic success or conversely the risk of economic failure associated with particular events or economic activities. By using risk analysis and focusing attention on how new scientific knowledge affects underlying probability distributions of events, scientific research output can be evalutated in terms of its simulated effects on economic decision-making criteria.

## ILLUSTRATING OUTPUTS OF SCIENTIFIC RESEARCH

This paper assumes that economic impacts of scientific research derive from new knowledge about possible outcomes of economic activities or events in nature. In general, such knowledge is probabilistic, having some degree of associated randomness or uncertainty. New knowledge produced by scientific research, including new data, theory, and discovery, provides new information about the range and likelihood of possible outcomes. Scientific research can produce new knowledge that increases certainty about specific outcomes or that reveals information about outcomes that were never previously anticipated. Knowledge about outcomes of economic activities or events in nature may be illustrated generally as probability density functions. Evensen (1977) and Kislev (1977) used probability distributions of possible outcomes to describe how agricultural research contributed new knowledge, using the example of research on sugarcane varieties and how it shifted the distribution of possible economic values that could be obtained from available sugarcane varieties.

Figure 1 illustrates two general and distinctly different impacts of new knowledge on anticipated outcomes of events and economic activities. First, new knowledge has an impact on perceived randomness or uncertainty about outcomes. For example, by increasing certainty, new knowledge may narrow the estimated probability density functions for outcomes of economic activities or events (Figure 1a). In this case, new knowledge has not changed our understanding of the most likely outcome but has greatly increased the precision with which we can predict and select that outcome. Second, scientific research may lead to discovery of alternative outcomes that were not previously anticipated. This is illustrated in Figure 1b by a shifting of the probability density function mode from A to B. Both impacts of scientific research may occur together and both are valuable in economic decision making. It is valuable to increase certainty about outcomes of economic activities or events, and it is valuable to discover or develop alternative outcomes for economic activity. In summary, the output of scientific research is new knowledge that provides greater certainty about specific outcomes or an understanding of unanticipated outcomes.

A conceptual example of these impacts is provided by forestry research and its

impacts on forestry decision making. Forestry research provides new knowledge that increases certainty about performance of existing silvicultural practices and promotes development of new techniques and silvicultural materials. Greater certainty in silviculture is provided by research in such areas as forest mensuration, growth modeling, forest survey, and research on forest ecology. The application of such research leads to greater certainty about outcomes of economic activities and events in forestry, as illustrated conceptually in Figure 1a. At the same time, research in forestry results in innovation and discovery of new techniques and materials for application in forestry, as with development of new hybrid tree species and discovery of biological mechanisms. As illustrated conceptually in Figure 1b, innovation and discovery have shifted available modes of economic activity in forestry. Both effects can have profound implications for economic decision making in forestry.

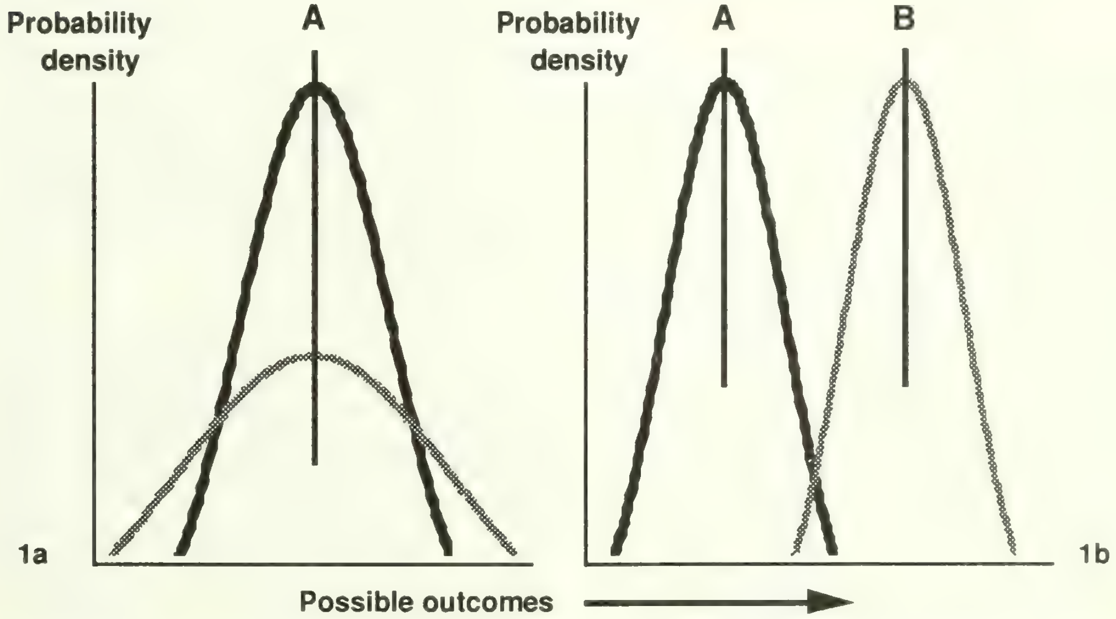


Figure 1. Possible impacts of new scientific knowledge. 1a. New knowledge can narrow the probability density for anticipated outcomes. 1b. New knowledge can lead to a discovery of alternative outcomes.

## EVALUATING ECONOMIC IMPACTS OF SCIENTIFIC RESEARCH USING RISK ANALYSIS

This section outlines a stepwise procedure by which risk analysis and Monte Carlo simulation can be applied to the problem of evaluating the impacts of scientific research on economic decision-making criteria. (This paper does not attempt to describe methods of risk analysis or Monte Carlo simulation; the text by Hertz and Thomas (1983) or other literature on the subject can provide further details.) Figure 2 illustrates the proposed evaluation steps.

•Step 1. After selecting an area of scientific research for evaluation, identify the kinds of practical new knowledge that the research produces or is expected to produce.

For example, if one were evaluating scientific research in forest ecology, one might identify practical new knowledge about factors that constrain or influence timber growth and timber mortality in particular forest ecosystems.

•Step 2. For each kind of practical new knowledge identified, identify events related to economic activities about

which the new knowledge provides greater certainty, innovation, or discovery about possible outcomes.

For example, in the area of forest ecology research, one might identify biological events, such as timber growth and mortality, that are related to economic activities such as investment in timber stand improvement, investment in timber regeneration, or investment in forest protection. New knowledge about those biological events can provide greater certainty, innovation, or discovery about possible outcomes of those economic activities.

•Step 3. For the principal events underlying the economic activities, describe preexisting knowledge about possible outcomes by estimating the probability density functions for event outcomes as they are anticipated prior to the scientific research.

For example, in the area of forestry, one could define preexisting knowledge about biological events such as timber growth or timber mortality by estimating the probability distribution for possible outcomes of those events as they are understood or anticipated prior to the scientific research. The probability distributions would show the range and likelihood of various outcomes that are anticipated with prior knowledge about factors influencing those events.

•Step 4. Use a rational economic decision-making criteria to describe consequences of economic activities, by defining an economic function across the range of possible event outcomes that are anticipated prior to the scientific research, and use Monte Carlo simulation to simulate the range and likelihood of economic consequences. Simulated economic consequences will show the likelihood of economic success and the risks of economic failure that are anticipated for economic activities prior to the scientific research.

For example, in the forestry area, one could use a traditional economic decision-making criterion such as net present value of forestry investment activities, with the economic criterion expressed as a function of event outcomes such as timber stand mortality and rate of growth. Once the appropriate mathematical function is defined, Monte Carlo simulation would be used to predict the range and likelihood of various economic consequences based on the probability distribution of events estimated in Step 3. Results will show the anticipated range and likelihood of net present values for forestry investments as they exist prior to the scientific research.

•Step 5. Describe impacts of new knowledge, typically as either a narrowing or shifting of the probability density functions for outcomes of events, by estimating the new probability density functions for possible outcomes as they exist or are anticipated to exist after the research is completed. New outcome distributions will reflect new scientific knowledge about outcomes, including greater certainty and development of alternative outcomes.

For example, in the forestry area, one could define new (postresearch) knowledge about possible timber stand mortality or rate of growth by estimating new probability density functions for possible outcomes of those events. The probability density functions would show the new range and likelihood of events that are possible with new research knowledge, including greater certainty about outcomes and discovery of alternative outcome possibilities for timber growth and mortality.

•Step 6. Use the same economic criteria and Monte Carlo simulation technique as employed in Step 4 to simulate the range and likelihood of economic consequences associated with outcomes anticipated in Step 5. Simulated economic consequences will show the risks of economic failure and the likelihood of economic success that are possible for economic activities after the research is completed.

In the forestry area, one would use the same functional relation defined in Step 4 between economic criteria, such as net present value, and outcomes of underlying events. One would substitute the new distributions of possible outcomes of

events defined in Step 5 and then repeat the simulation as performed in Step 4. Results will show the possible range and likelihood of net present value for forestry investments as they would exist after the scientific research is completed.

•Step 7. Compare results of Step 6 with results of Step 4 to estimate the impacts on economic decision-making criteria of the scientific research. Impacts should be analyzed in terms of reduced risk of economic failure or increased probability of economic success, by comparing the estimated probability distributions of economic consequences derived from Steps 4 and 6.

Using this procedure, the impact of scientific research on economic decision-making criteria can be evaluated, regardless of whether the impact is to increase the certainty of knowledge about possible outcomes or to provide knowledge about previously unanticipated outcomes. Both impacts will influence the risk of failure or likelihood of success for economic activities. As such, results of

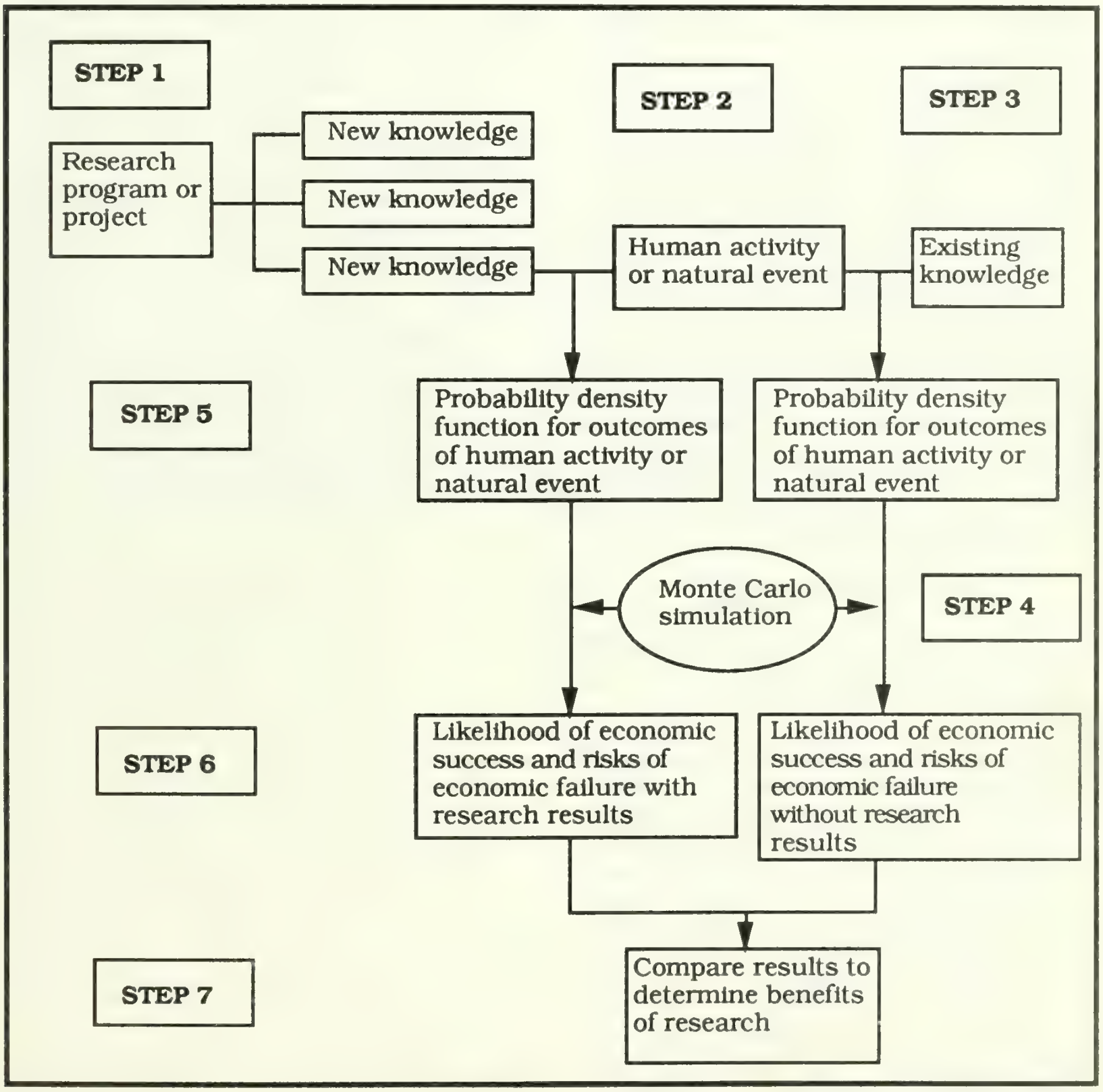


Figure 2. A method for evaluating the impacts of scientific research on economic decision-making criteria.

analysis will illustrate the economic decision-making consequences of scientific research in terms of both greater certainty about economic consequences and selection of new modes of economic activity.

## CONCLUDING REMARKS

Outputs of scientific research may be evaluated by examining both the impact of greater certainty about outcomes of events and the impact of discovery of unanticipated outcomes. Knowledge about possible outcomes of events in nature or outcomes of human activities are represented by estimated probability density functions. Such functions may be described both as they exist prior to scientific research and as they exist or would exist after scientific research is completed. Given economic decision-making criteria that depend rationally on those outcomes, the methods of risk analysis and Monte Carlo simulation can be used to estimate the range and likelihood for economic consequences both before and after the research is completed. The impact of research on decision-making criteria may be evalutated by comparing risks of economic failure or probabilities of economic success between situations before and after research is completed.

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# EXPERIENCES WITH A SCIENTIFIC RESEARCH STUDY GROUP

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**Abstract**. In November 1982, personnel with the North Central Forest Experiment Station at East Lansing organized a scientific study group. The general objective was to discuss and evaluate "Ideas and Methods Leading to More Effective Research." Since then, the group has met at 2- to 3-week intervals with a fluctuating attendance of from 5 to 18 people, depending upon the topic discussed and the members' schedules.

Three elements had to be present before forming the study group: complete backing and participation of the work/project supervisors; a conscientious group leader; and a nucleus of four to eight interested members. These elements were essential not only for establishing the study group but also to keep it going.

Subject material has covered a diversity of topics including (in no particular order): methods of formulating problem statements and hypotheses;quality research circles; "creation science"; using a major library to advantage; science within government, research quality awards, hunting Big Foot — legitimate science?; a defense of ontology (metaphysics); scientific rewards; implications of archetypal symbology; scientific strategies; and partial to complete coverage of four books that emphasized the meaning and definitions of science, the foundations of behavioral research, and the practice of social research.

Topics are chosen by group consensus. Some group members are most comfortable within a well-structured syllabus, almost a classroom situation. Others become bored with a rigorous structure and opt for changing topics from session to session. One of the duties of the group leader is to strike a topic balance. Additional duties of the group leader include appointing a discussion leader for each session, finding outside speakers when available, posting minutes and agendas, and making background readings available.

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Presents fifteen papers and four abstracts in five topic areas: The research process, Forestry constructs and innovations, Interdisciplinarity, Emerging research areas, and Assessing research productivity, quality, and motivating scientists.

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KEY WORDS: Research methods, research strategies, interdisciplinarity, research productivity, research rewards, Delphi, organization theory.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION

United States Department of Agriculture

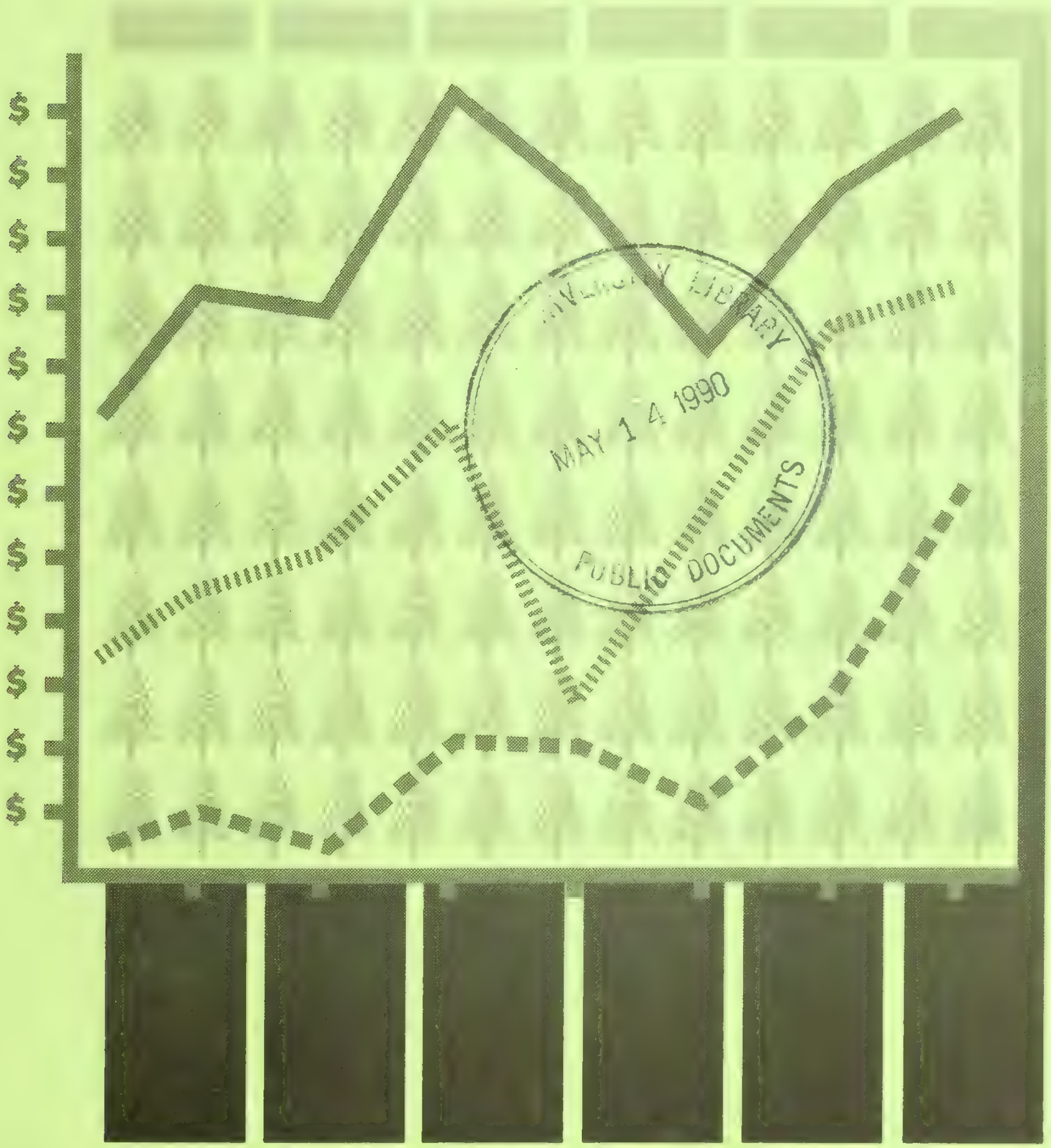
Forest Service

North Central Forest Experiment Station

General Technical Report NC-136

# The Economic Impacts of Lake States Forestry: An Input-Output Study

Larry Pedersen, Daniel E. Chappelle and David C. Lothner



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# THE ECONOMIC IMPACTS OF LAKE STATES FORESTRY: AN INPUT-OUTPUT STUDY

**Larry Pedersen, Daniel E. Chappelle, and David C. Lothner**

## HIGHLIGHTS

- The forest product industries in the Upper Lake States had sales in excess of $15 billion in 1982, nearly 8 percent of total manufacturing sales in the region.
- The growth rate in forest product sales between 1985 and 1995 is expected to exceed the region's overall economic growth rate by more than 20 percent. By the year 1995, wood product sales are expected to exceed $22 billion in real terms.
- The forest product industries in the Upper Lake States employed more than 150,000 in 1982, with wages and salaries estimated at $3.5 billion. By 1995, the number of employees is expected to grow to 225,000 with wages and salaries at $5 billion.
- The use of wood for energy in the region will produce nearly 10,000 new jobs between 1985 and 1995.
- The use of forested areas for outdoor recreation accounted for more than $2 billion (1982 dollars) of the region's economy in 1985. Adding the multiplier effect, this expenditure generated more than 80,000 jobs and $1.2 billion in personal income. Between 25 and 35 percent of these totals came from nonresidents.
- Although adequate forest resources exist to sustain the economic growth rates projected in this study, continued expansion by wood processing industries could eventually exhaust the surplus timber supplies and raise stumpage prices significantly. Real stumpage price increases are already occurring for some species.
- More intensive forest management could permit higher sustainable harvest levels while improving the timber quality and increasing opportunities for nontimber forest uses.
- Future public and private cooperation on a regional basis could help anticipate potential supply problems and avoid conflicts over forest use.

**Larry Pedersen** is a Graduate Research Assistant and **Daniel Chappelle** is a Professor of Resource Development and Forestry, Michigan State University, East Lansing, MI; and **David Lothner** is an Assistant Director with the North Central Forest Experiment Station, St. Paul, MN.

## INTRODUCTION

This report describes current (1985) and projected (1995) levels of forest-related economic activity in the three-state area of Michigan, Minnesota, and Wisconsin (the Lake States), and their impacts on other economic sectors based on a regional input-output (I/O) model. We analyze direct economic impacts associated with three forms of forest resource uses—forest products, wood energy, and outdoor recreation—as well as the economic multiplier effects. Our goal is to provide Lake States planners, policy makers, and others with data, information, and analytical tools for measuring the economic contributions of Lake States forests. This information will enhance their capability to assess alternative planning strategies in the next round of comprehensive planning.

The Lake States region, with about 41 percent of its total land area forested, is one of the most densely forested areas of our nation. The many resources provided or associated with these forest lands are, once again, gaining recognition for the important role they presently play and the future promise they offer to the region's economy. Although the relative economic contributions of today's Lake States forests will not likely be as important to regional economic development as the forests during the white pine era (1869 to 1900), the contribution will, undoubtedly, be major.

State and Federal forestry agencies within the Lake States have been involved with comprehensive forest

planning activities since the early 1970's. These Lake States planning efforts intensified during the early 1980's in response to the Forest and Rangeland Renewable Resources Planning Act of 1974 as amended by the National Forest Management Act of 1976 (Gray *et al.* 1985). During this period, forest resource managers and planners developed a consensus regarding the quality, quantity, and form of information necessary versus that available for planning purposes (Lewis and Ellefson 1983). The lack of consistent, adequate information was a substantial barrier to the development of long-term forest management strategies and policies necessary for assisting economic development and community stability across the Lake States region.

Measurement of Lake States forest resources is an ongoing process. Recently, the scope of that process has been extended well beyond the traditional USDA Forest Service reports on forest area, the physical availability of standing timber, and wood biomass inventory data, to studies of forest product flow and impacts on the region's economy. These have been promoted by legislation mentioned above, a substantial literature on impact assessment (such as the USDA's Forest Service input-output model IMPLAN), as well as state economic and environmental interests.

Gray *et al.* (1985) assembled data on the production, consumption, and trade of primary wood products in the Lake States. This and similar information is necessary to bridge the gap between inventory data and the sector data in I/O analyses. A series of studies on the timber products economy of Michigan has also recently been published. The final report of this study, "Economic Impacts of Michigan Forest Industries: A Partially Survey-Based Input-Output Study" (Chappelle *et al.* 1986), was a precursor of this regional report.

The economics of nontimber forest resource uses have also been examined, although far less frequently than conventional forest products. Employment Research Associates (1985a and b) estimated the economic impacts stemming from wood energy use in a seven-state Great Lakes region. Proceedings from a May 14-16, 1984 conference, "Assessing the Economic Impacts of Recreation and Tourism," (Propst 1985), contain both theory and applications for a study analyzing the impact of an emerging forest resource use. For a fairly complete listing of forest-related impact assessments, see "Spatial and Regional Analysis Methods in Forestry Economics: An Annotated Bibliography" (Obiya *et al.* 1986).

The benefits from forest resources are often viewed as having fairly localized impacts. While it is true that the economic health of many rural areas in the Lake States is closely tied to the products and services contributed by the surrounding forests, the economic contributions of the forests to one locale will produce ripple effects felt throughout the region.

This report expands the available information base on the Lake States forest resources and their contribution to the region's economy. In it we give an overview of the region's forest resources, describe the methods used in our analysis, present results, and close with a discussion of the results. The appendices provide additional information on methods and interpretation of the results.

## LAKE STATES FOREST RESOURCES

The distribution of the 50 million acres of forest land in the Lake States region is fairly evenly divided among the three states—Michigan 18.2 million acres, Minnesota 16.6 million acres, and Wisconsin 15.3 million acres[1]. About 91 percent or about 45.6 million acres are considered timberland (fig.1). Timberland is forest land capable of producing timber for wood products as well as wildlife, water, and recreation. The other 4-1/2 million acres of forest lands are either set aside for wilderness or parks, or are not physically capable of producing commercial timber. The majority of this noncommercial acreage, about 67 percent or 3 million acres, is found in Minnesota.

In total, the Lake States have experienced a 12 percent reduction in timberland between 1952 and 1987. Minnesota has experienced the most significant reduction, about 22 percent, largely as a result of park and wilderness expansions. Michigan's 9 percent decline is due primarily to urban and related development in the southern lower peninsula. In contrast to the other two states, Wisconsin's timberland has remained relatively constant. A modest 1.5 percent increase from 1977 to 1987 has been primarily due to farmland in the southern part of the state reverting back to forest land.

[1] *Statistics for this section were derived from the USDA Forest Service North Central Forest Experiment Station 1987 RPA data. We wish to thank W. Brad Smith for providing the data.*

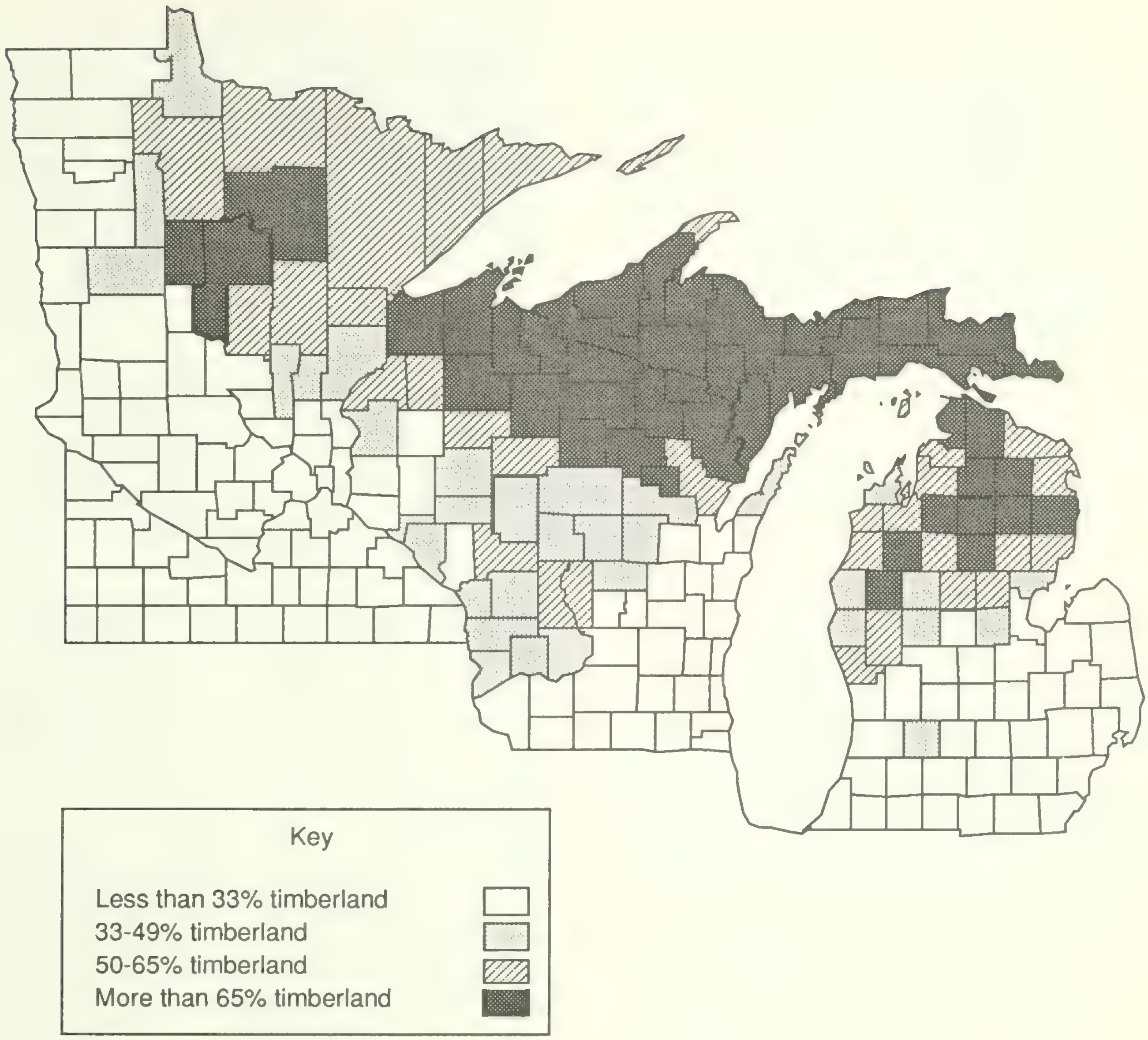


Figure 1.–*Percent of county area classified as timberland, Lake States,*

Nearly 40 percent of timberland in the Lake States is publicly owned, with state and county ownership accounting for over 25 percent of the total (fig.2). Thus, state and county forestry agencies play a major role in providing resources for industrial wood products, fuelwood, and recreation economic development opportunities.

There are presently 6 major forest types in the Lake States. Aspen-birch dominates the region, covering about one-third of the timberland area. This is followed by the maple-beech-birch type which covers another one-quarter. The spruce-fir (15 percent), oak-hickory (12 percent), pine (8 percent), and elm-ash-cottonwood (7 percent) types make up the remaining cover. Only about 1 percent of the timberland is classified as nonstocked. While there are many similarities among the individual states in the region, there are some differences in cover types. Aspen-birch (50 percent) is the dominant cover type in Minnesota whereas maple-beech-birch (36 percent) is the predominant type in Michigan. Wisconsin is dominated by roughly equal proportions of these two forest types.

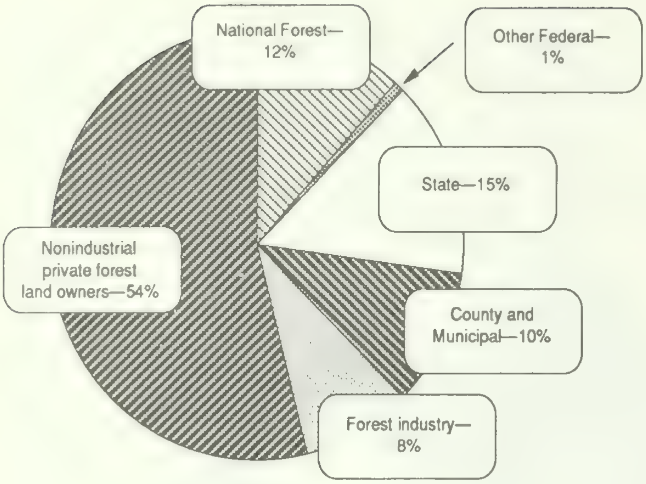


Figure 2.–*Distribution of Lake States timberland among ownership classes.*

In spite of a slight reduction in commercial forest acreage in the Lake States over the past 10 years, total growing-stock volume has continued to increase. The 1987 total growing-stock volume was estimated at 50.8 billion cubic feet. This is an increase of 15 percent over the growing-stock volume estimate in 1977 and a 175 percent increase since 1952 (fig. 3). As in the past, hardwoods still account for nearly three-fourths of the growing-stock volume in the region.

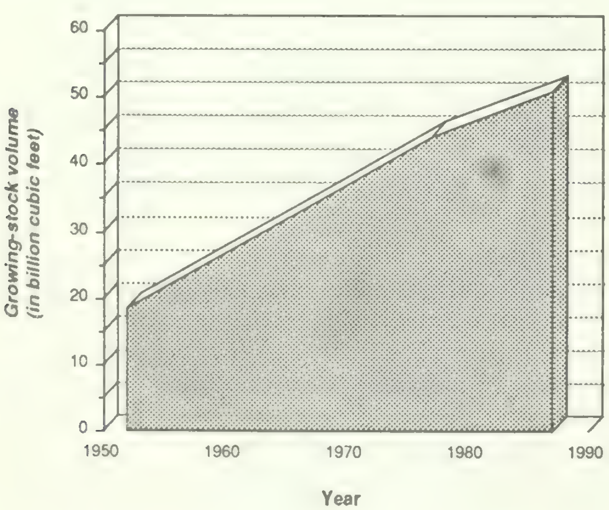


Figure 3.–*Despite a decline in timberland area, growing-stock volume in the Lake States has increased.*

The productivity of Lake States forests has also increased. The regional average for growing-stock volume was estimated at 1,114 cubic feet per acre in 1987. This is about a 21 percent increase from 1977 and results from an increase in timber size as well as more intensive management. The national average for growing-stock volume per acre in 1977 was 1,466 cubic feet, so the Lake States regional average is still likely to be well below the national average. The annual growth of growing-stock volume in the Lake States is 37 cubic feet per acre, an increase of approximately 3 cubic feet per acre over the last 10 years. This is still well below the potential average productivity level in the Lake States which is estimated at 58 cubic feet per acre per year. The average potential site productivity is the volume of timber the average fully-stocked natural stand could produce at culmination of mean annual increment. Thus, there still appear to be significant opportunities to increase timber productivity.

Over 25 percent of timberland in the Lake States is comprised of stands 40 to 60 years old and another 20 percent is 60 to 80 years old. The aspen-birch type, a relatively short-lived forest type, represents nearly 40 percent of the timberland acreage in these two age classes. Thus many of these stands are beginning to deteriorate or are on the verge of deterioration.

Gray *et al.* (1986) describes how this deterioration implies a lost opportunity to utilize these resources and a failure to achieve the physical capability of the land base to produce timber. They go on to address this skewed age class distribution by asking, "how can the wall of wood now occupying the Lake States forest be effectively utilized without entailing a subsequent decline in timber resource availability?" Assumptions used in long-range projection models about future species composition and increased growth rates after harvesting the relatively slow-growing, mature timber can carry significant implications. However, no explicit assumption regarding species composition or growth rates were adopted for this study's forecasts.

As with growing-stock volume, growing-stock growth has steadily increased. Throughout the period, growth has exceeded removals. In 1987, total Lake States net annual growth was 1.7 billion cubic feet whereas removals were 0.9 billion cubic feet. Net annual growth of hardwoods and softwoods were about 1.2 and 0.5 billion cubic feet respectively. These compare to hardwood and softwood removals

of 0.7 and 0.2 billion cubic feet respectively. The difference between growth and removals has been reduced. Removals have increased substantially over the past 10 years, with expansions in both the pulp and paper industry, the structural particleboard industry, and the use of wood for energy. However, both hardwood and softwood growing-stock growth has increased. Thus, there still appear to be opportunities for further industrial expansion.

## METHODS

Existing estimates of forest-related activity were integrated with economic forecasts for use with the USDA Forest Service's I/O model IMPLAN[2]. No primary data were collected, rather secondary data sources were used to estimate current and projected economic activity with the three types of forest resource use considered in this study (wood products, energy production, and outdoor recreation). Because of differences in data availability, the methods used to prepare the IMPLAN input varied by forest resource use. In the following we discuss I/O models in general, then IMPLAN specifically, and finally the preparation of input for each sector.

### Input-Output Analysis

Input-output analysis describes the interdependence among sectors (industries) in a region, and is used to measure effects felt throughout an economy when demand or supply changes in one or more sectors. In this analysis, effects on the regional economy as a consequence of demand changes were studied. This type of input-output model is driven by final demand, and quantifies the effects of changes in the level of final demand on final payments, sales (gross output), and employment by sector. Final demand refers to household and government purchases, business investments, inventories, and exports. Final payments refer to the value added components of production costs, including wages and salaries (personal income); rents, royalties, and interest (property income); and indirect business taxes.

[2] *Input-output modeling dates back to Leontief's pioneering work in the 1930's. For more detail on Input-output analysis, see Miller and Blair (1985).*

Virtually any change in final demand will cause a series of transactions to ripple through an economy. Generally, to use an I/O model, we must first estimate final demands for all sectors of an economy for a given year. Using these estimates as inputs, the model forecasts output levels necessary from all industries to meet the forecasted levels of final demand. As a result, we can measure the direct, indirect, and induced effects associated with our estimates of changes in final demand. Direct impacts refer to economic effects in the sector from which the purchase is initially made. Indirect economic impacts occur from the transactions which must take place to provide the output purchased. Indirect impacts include a whole series of backward production linkages that are also referred to as intermediate purchases. Intermediate purchases are diminished by imports that result in transactions and impacts outside the region. Induced impacts stem from increased consumption by households made possible by the increased earnings from meeting the changes in new final and new intermediate demands.[3]

In most I/O analysis, impacts are assumed to occur within a year's time and can be measured in several economic dimensions in addition to sales, such as personal income and employment. These other measures are based on the ratios of these variables to output for each sector in the model's base year.

In addition, "multipliers" may be calculated for each of these economic variables, representing the analogous ripples from the initial increase in final demand. The model employed in this analysis calculates two types of multipliers, a Type I and a Type III, for sales, employment, and personal income. The Type I multiplier is the ratio of the direct and indirect impacts to the direct impact. The Type III multiplier is the ratio of all impacts (direct plus indirect plus induced impact) to the direct impact.[4]

[3] *The induced impact calculated by IMPLAN is different from traditional estimates of induced spending associated with a Type II multiplier. The IMPLAN induced effect is based on direct and indirect impacts causing changes in employment. These changes are used with ratios of employment to population to estimate population changes which are, in turn, multiplied by estimates of average per capita consumption to generate induced estimates. These induced estimates are then fed back through IMPLAN as final demands.*

[4] *The calculation and interpretation of multipliers is explained in Appendix A.*

For our I/O model, we used the USDA Forest Service's IMPLAN Model,Version 2.0 (USDA Forest Service 1983, 1985), maintained by the Forest Service at the U.S. Department of Agriculture's Fort Collins, Colorado Computer Center. IMPLAN's data base contains a detailed national interindustry table and estimates of final demand, final payments, sales, and employment by sector for each county in the U.S. In IMPLAN Version 2.0 these estimates are provided in terms of 1982 economic relationships. The model's economic sectors generally follow commonly used Standard Industrial Classification (SIC) codes. We used the model to develop economic impact estimates for a 48 sector three-state model.

The IMPLAN model is a nonsurvey I/O model. As such, it has to employ data reduction techniques to develop regional models from national data. Version 2.0 of IMPLAN adopts an approach pioneered by Benjamin Stevens and George Treyz, and incorporated in Regional Economic Modelling, Inc. (REMI) models. Regional purchase coefficients (RPCs), representing the proportion of local output purchased to meet local demand, are determined econometrically. Independent variables used to estimate the RPCs include the size of the region, regional wage levels, location quotients based on employment, and transportation costs. Primary data collected on forest product trade flows could be used to check the accuracy of IMPLAN's RPC estimates for forest product industries—thus indicating the extent to which forest product industries rely on indigenous material sources—but such primary data were not yet available for this analysis. In addition, the RAS method, which is an iterative balancing process, is used with Version 2.0 to reconcile inconsistent or incomplete data.

## Estimating Economic Impacts

### *Forest Products Industry*

The following steps were used to develop economic impact estimates for the forest products industry:

**Step 1. Select forest products industries to incorporate into analysis**—IMPLAN allows the user to select the level of industry aggregation and, thereby, the amount of sectoral detail in the model's results. The user is, however, somewhat constrained by the initial level of detail in IMPLAN's data base. For example, the IMPLAN data base does not adequately differentiate forestry services from agricultural and fishery services to permit distinguishing their economic impacts from each other. Another example is that IMPLAN's data base does not distinguish between hardwood and softwood veneer and plywood (SIC 2435 and 2436).

We selected 17 forest product industries to include as separate sectors in our 48-sector regional IMPLAN model (table 1). The selection of industries was based on several factors, including the size of the industry (smaller industries were combined with relatively similar industries to form an aggregate industry) and interest expressed by the three states' Department of Natural Resources and the USDA

**Step 2. Estimate growth in final demands for forest product industries, 1982-1995**—IMPLAN used 1982 as its base year. For our analyses we wanted to estimate the change in final demands between 1982 and 1985 and between 1982 and 1995 for use as inputs to IMPLAN. We drew on data from three sources: REMI (Treyz 1986), *County Business Patterns* (CBP) (U.S. Department of Commence 1981-1986), and Data Resources Inc. (DRI) (Data Resources Interindustry Service 1985). Each source could give us only a portion of what we needed as inputs for IMPLAN. For each state, we had REMI forecasts of 1984, 1985, and 1995 intermediate and final demands for output and employment, but for only 3 aggregated (SIC 2-digit) forest product industry sectors. The DRI study forecasted output and consumption trends in 39 disaggregated (SIC 4-digit) forest product sectors between the years 1984 and 2000, but only include secondary wood processing industries (i.e., the logging sector was not included). The DRI study also lacked state trend data from Minnesota and Wisconsin—these two states were included in a six-state region which also included Michigan, Illinois, Indiana, and Ohio. CBP for each state provided employment data.

By combining and massaging these data, we were able to estimate the rates of change we needed. The DRI data were used to allocate the REMI final demand estimates for the 3 aggregated forest product sectors in each state to the 17 forest product sectors of interest in this study. The REMI/DRI final demand estimates for 1984, 1985, and 1995 were used to calculate change in final demand between 1984 and 1985 and between 1984 and 1995. To move from IMPLAN's 1982 base year to 1984, we used CBP estimates of employment change between

1982 and 1984, and multiplied the estimated employment change by ratios of employment to final demand, calculated using REMI and DRI data, to derive changes in final demands between 1982 and 1985 and 1982 and 1995.

**Step 3. Estimate growth in final demands for other sectors in the model**—Estimates of final demand for sectors not involving forest products were required to complete the picture of the interaction between the forest product sectors and other sectors of the region's economy. For private, nonfarm, nonforest industries, IMPLAN 1982 base year final demand values were multiplied by REMI-derived growth ratios to estimate projected 1985 and 1995 final demands for these sectors.

REMI estimates of employment in the government and farm sectors indicated stable employment over the period of interest, therefore we assumed no appreciable change in final demand for these sectors and used IMPLAN base year values over the forecast period.

**Step 4. Construct IMPLAN model for the region**—A three-state region, 48-sector IMPLAN model was constructed following the steps described in the IMPLAN User's Guide (USDA Forest Service 1983). Since IMPLAN Version 2.0 was still in the development stage at the time of this study, it was necessary to correct for errors in reported trade patterns for certain sectors (approximately 10 percent of the sectors required adjustment). These errors were detected using supplemental REMI data. After adjustments, the IMPLAN and 1982 REMI state estimates of total final demands differed by less than 1 percent.

**Step 5. Apply estimated final demand growth trends to IMPLAN base year final demands to derive sales, personal income, and employment estimates**—The estimated growth in final demands from 1982 to 1985 and 1995 was used with the IMPLAN model to arrive at 1985 and 1995 regional projections of forest products industry economic activity. Sales growth rates and comparisons with regional manufacturing and total economy performance were then calculated.

*Wood Energy*

Estimates of regional economic impacts from wood energy are based on a 1985 study done for the Council of Great Lakes' Biomass Energy Program (Employment Research Associates 1985a and b). To summarize, the report found that customers turn to wood because it is a cost minimizing substitute for conventional fuels. The pulp and paper and the wood products industries are the major industrial users. For these industries, wood energy not only reduces their energy costs, but also reduces their waste disposal costs and avoids environmental degradation from other disposal methods. These industries are able to produce useful energy from wood wastes, and at the same time comply with Federal and State regulations which discourage open burning and landfilling of wastes.

The Great Lakes Biomass Energy Program study further found that wood energy use responds strongly to any changes in the cost of energy to end users. They note that it does not necessarily follow that lower crude oil prices will lead to lower costs for consumers. In fact, despite lower prices for crude oil, end-use prices have continued to edge up over the last few years and are forecast to increase moderately through the 1985-1995 period. Most private and government energy forecasters believe that these increases will occur even with stable oil and natural gas prices. The report concluded that wood will continue to be a cost minimizing choice for a significant number of residential, industrial, commercial, and public sector consumers. The news to consumers, however, is not all good—the rate of conversion to wood energy will accelerate if fossil fuels become more expensive, resulting in even higher energy costs for the end-user.

Using IMPLAN Version 1.1, the Biomass Energy Program study generated three wood energy economic impact scenarios in 1985 and 1995 for a seven-state Great Lakes region. Use of wood for fuel greatly increased during the 1970's, spurred on by dramatic increases in conventional fuel prices. Growth rates diminished in the mid-1980's as fossil fuel prices stabilized and, in some cases, declined. In light of fossil fuel price decreases and some reported energy system conversions back from wood to conventional fuels since the original Biomass Energy Program estimates were compiled, we used final demand estimates for Michigan, Minnesota, and Wisconsin associated with the report's low to moderate wood energy use estimates. These final demand estimates were used with IMPLAN Version 2.0 multipliers from our 48-sector model.

**Step 1. Determine area to be considered "wildland"**—The objective of this portion of the analysis was to measure the economic impacts of outdoor recreation in the more heavily forested areas ("wildland") of the three Lake States. Although outdoor recreation spending by residents and nonresidents plays a vital economic role in large areas within each state, estimating economic impacts of outdoor recreation is difficult. The impacts of outdoor recreation activities have been measured in numerous ways for different purposes, but none matched the needs of this analysis.

We chose to estimate regional impacts from recreation only in counties that were 30 percent or more forested, based on recent USDA Forest Service inventory estimates (fig. 4). However, since much of the recreation data was reported by sub-state regions consisting of multiple counties, a few counties slightly more than 30 percent forested were excluded and a few counties slightly less than 30 percent forested were included.

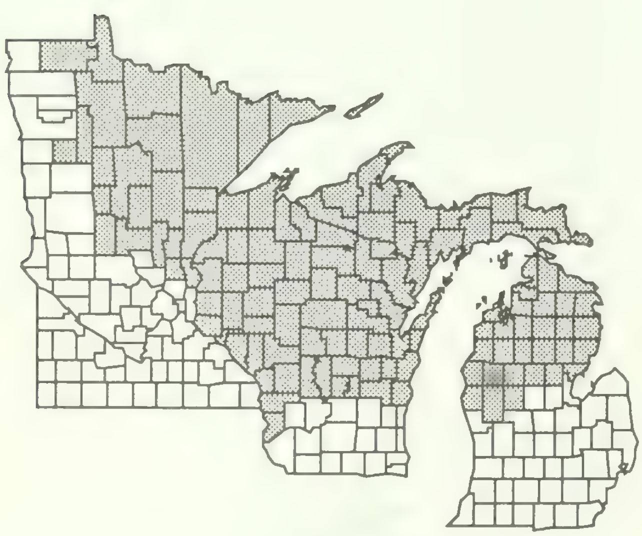

Figure 4.–*Outdoor recreation area included in this analysis.*

**Step 2. Assemble information on both resident and nonresident recreation participation in the region's designated wildland**—Outdoor recreation considered in this analysis includes:

| | |
|---|---|
| bicycling | developed camping |
| primitive camping | hiking |
| backpacking | pleasure walking |
| horseback riding | swimming and sunbathing |
| boating | canoeing |
| fishing | hunting |
| downhill skiing | cross-country skiing |
| snowmobiling | sightseeing |

This list includes several activities that are only nominally related to the region's forest resources, such as swimming, bicycling, and downhill skiing; however, this is in line with the focus of our study, which is to estimate total outdoor recreation economic impacts in the forested regions of the three states.

Sources of information on regional resident and nonresident recreation included the three states' SCORP's (State Comprehensive Outdoor Recreation Plans); the 1980 National Survey of Fishing, Hunting and Wildlife-Associated Recreation (USDI Fish and Wildlife Service 1982); and Travel and Tourism in Michigan: A Statistical Profile (Spotts 1986). These sources were used to construct a profile of regional recreation activity for 1985.

Due to the unreliability of existing recreation participation data, no effort was made to quantify 1995 recreation spending impacts. The 1985 base year data have many gaps and may not be dependable. Also, after substantial growth in the 1960's and 1970's, participation in many forms of outdoor recreation flattened out or were at depressed levels in the early to mid-1980's. It appears a number of markets are saturated; however, new markets should not be ruled out.

**Step 3. Develop expenditure profiles for recreation participation**—At the time of this study, no complete, consistent, and reliable outdoor recreation data base existed that could be used in an economic impact analysis of a sub-state region of a multi-state area (such as the more heavily forested areas of our three-state region). The lack of standardization in data reflects different objectives under which the data is gathered to measure tourism, state park attendance, or the multiple demands on lakes or streams.

Units of measurement may be simple head counts, number of trips, "occasions," recreational visitor and activity days, and hours spent in the activity. Studies also include and exclude different types of recreationists, again, depending on study objectives.

There are many other recreation analysis pitfalls. The sheer diversity of activities and recreationists makes impact estimation difficult. Double-counting is a risk when using multiple sources of data as in this study. Fishermen camp and campers fish; separating out what multiple data sources have included may be impossible. Typical spending categories mentioned in studies frequently do not fit the SIC codes used in impact analysis. Spending will also differ depending on the recreationist's origin and destination, lodging, activities engaged in, and the recreation season.

Analysis of the literature led us to the conclusion that detailed recreation expenditure data from Minnesota were most appropriate for purposes of this study. These data included estimates of both resident and nonresident average expenditures in 1984 dollars per recreation activity occasion (Kelly and Becker 1985). In addition, we obtained from the Minnesota Department of Natural Resources (1986) survey-based estimates of total Minnesota resident and nonresident outdoor recreation spending by IMPLAN sectors for 1985-1986.

Table 2 indicates how a recreationist's average dollar is spent among sectors included in the 48-sector regional IMPLAN model, based on the detailed surveys of recreation expenditures in Minnesota's forested areas. Because the distribution among sectors follows input-output conventions it differs from many recreation spending profiles. Retail and wholesale sector estimates reflect the shares of purchases in other sectors which are attributable to these services. For example, input-output tables do not have retail gasoline sectors. Every dollar for gasoline has to be apportioned to labor, profits, taxes, petroleum production, transportation services, and other sectors, including a portion to retail services. The same is true of spending for apparel, lodging, food, and restaurants. There will be some retail trade component, or "margin" as it is referred to, in virtually any type of recreation spending. Recreation spending profiles often do not separate out such charges from the primary good, *e.g.* food, hotels. This recreation spending profile is also different from others because it is an average of many types of lodging expenses, recreation activities, seasons, lengths of stay, modes of transportation, and other variables.

**Step 4. Combine expenditure profiles with participation rates for use with multipliers derived from the 48-sector, regional IMPLAN model**—The average Minnesota spending estimates, deflated to 1982 values, were combined with regional resident and nonresident participation rates for Michigan and Wisconsin to arrive at resident and nonresident outdoor recreation spending in Michigan and Wisconsin. This spending was combined with the Minnesota patterns of spending by sector to derive total regional recreation spending. Finally, the spending by sector was multiplied by the corresponding sectoral IMPLAN Type III multipliers to derive estimates of recreation impacts. The results, therefore, indicate how participation in outdoor recreation activities within the forested regions of the three states impacts the entire three-state region, assuming the spending distribution pattern of Minnesota's recreationists. The estimates represent the impact of recreation expenditures at or near the recreation site. As with most recreation studies, we did not include major equipment purchases (*i.e.*, boats, campers, etc.). Large recreational equipment items may be used both within and outside of the forested study area, and, in some cases, for nonrecreational purposes. Including major recreational equipment expenditures could double the impact estimates; however there is little equipment use data available to justify allocating a particular percentage of such expenditures to the study region.

## RESULTS

### Forest Products Industry

*1982 Base Year Estimates*

IMPLAN 1982 estimates of sales, employment and personal income by forest products sector are shown in table 3. Total forest products industry sales, employment, and personal income for the region account for between 7 and 9 percent of the total for all manufacturing industries. However, the forest products industry share of total economic activity is significantly higher for many heavily forested substate areas. In total, the forest product sectors in Michigan, Minnesota, and Wisconsin had combined sales of more than $15 billion and were responsible for more than 150,000 jobs in 1982. Personal

income directly associated with this employment amounted to $3.5 billion. The largest share of this economic activity was in the pulp and paper sector (SIC 26), which accounted for the majority of total forest product sales, employment, and personal income in 1982.[5]

*1985 and 1995 Sales Growth Projections*

The sales and sales growth rates reported in table 4 in real terms (1982 dollars) are the result of both final demand growth estimates and the IMPLAN model's input-output relationships. The projected growth in sales implies that significant economic opportunities exist in the forest product industries. The forest product industries in the three states are estimated to grow faster than the overall economy between 1985 and 1995. During this period, the average annual sales growth rate of the forest product sectors is projected to be 2.83 percent in comparison to the overall regional economy growth rate of 2.35 percent. Evidence from CBP employment data for 1982 through 1985 and the available information on forest product industry investment plans for the near future suggest these growth rates are reasonable and not overstated.

Sales growth rates for all lumber and wood products industries (SIC 24) and paper and allied products industries (SIC 26) are projected to be quite similar for the 1985 to 1995 period. The two wood furniture (SIC 25) sectors are estimated to have an even higher combined annual growth rate of almost 4 percent in this period.

It is instructive to note the estimated growth for several other specific sectors. Logging camps and contractors is the sector that should best reflect trends in forest harvests. Timber supply problems could materialize if this sector's estimated 4.75 percent output growth rate for 1982 to 1985 is maintained. However, the 1985 to 1995 estimated sales growth rate of 2.74 percent for logging camps and contractors is below currently estimated timber growth rates in the three states. This implies that the region's forest resources could potentially sustain forest product sales significantly above the levels shown in table 4, even without changes in forest management.

The paper mills sector is the largest forest-related industry in the three-state region in terms of sales, employment, and income. It is estimated to have an annual sales growth rate of 3.27 percent during 1985 to 1995 period, almost a full percentage point above the annual growth rate of 2.35 percent for the region's overall economy. The projected 1995 sales for all pulp and paper industries (SIC 26), in excess of $15 billion, are slightly greater than all 1982 forest product sales combined.

The lumber and wood products sector (SIC 24) estimated to have the lowest annual growth between 1985 and 1995 is an aggregation of hardwood and softwood veneer and plywood as well as structural members. This sector's low growth is anticipated because other new products, such as waferboard and oriented strand board, have significantly penetrated the traditional veneer and plywood markets. The particleboard sector, including waferboard and oriented strand board, stands out within the sector for its spectacular growth — an annual sales growth rate of 8.19 percent between 1985 and 1995. However, this growth starts from a relatively small 1982 sales base of $84 million.

*1985 and 1995 Employment and Personal Income Projections*

Table 5 shows the employment and personal income that would be associated with the levels of sales presented in table 4. The two columns of coefficients indicate the IMPLAN 1982 ratios of jobs and employment compensation to sales. For example, the coefficients of 7.6747 and 0.1980 indicate there are approximately 767 jobs and $19.8 million in wages and salaries for every $100 million in output by logging camps and contractors.

Variations among these sector coefficients reflect several factors including relative labor-intensity and wage levels, the mix of technologies and plant sizes, employee skill levels, and the sector's labor market. Larger coefficients do not necessarily indicate that

[5] *Surveys of forest product firms in the Lake States indicate that secondary sources of employment data significantly underestimate the number of jobs in the region's forest industries. This has been found to be particularly true with primary forest industries in both Michigan and Wisconsin. Unfortunately, we cannot correct for this problem in this analysis without additional survey data. Based on the Michigan survey (James et al. 1982), the total forest products industry employment estimates adopted from IMPLAN may be as much as 15 to 25 percent below actual employment levels.*

the industrial sector is more attractive, but they do indicate that there are more jobs or income associated with its sales. Greater mechanization and employment of the most advanced technologies may well make an industry more economically sound, but could be expected to reduce these labor-related coefficients.

Although lumber and wood products industries had half the number of employees pulp and paper industries had in 1982, by 1985 it is estimated to have closer to 60 percent of the number of pulp and paper employees. Although the particleboard sector will experience phenomenal growth in employment and personal income, it will still account for less than 2 percent of the 1995 employment and personal income of all the forest product sectors in the region.

*Indirect and Induced Effects*

Other indicators of the economic importance of forest-related industries are the indirect and induced sales, employment, and personal income associated with meeting demands for forest products. Tables 6, 7, and 8 present economic impact components and multipliers derived from the USDA Forest Service's IMPLAN model for the region's forest products sectors. The estimates apply only to the region considered in this analysis.

The impact categories (defined in the Methods section, above) and their sum ("Total") appear for employment and personal income in tables 7 and 8, respectively. They indicate what sales, employment, and personal income changes occur per unit of change in a sector's final demands. The Type I and Type III multipliers are also presented. This delineation of impact estimates is in line with conventional reporting of economic impacts which often presents results both with and without the induced impact included. Appendix A presents a detailed illustration of how to interpret the impact estimates.

Total estimates of the impacts for 1985 and 1995 are presented in tables 9 through 11. These estimates were derived by multiplying the Type I and Type III multipliers in tables 6, 7, and 8 by the corresponding estimates of direct sales, employment, and personal income for 1985 and 1995 presented in tables 4 and 5.

**Wood Energy**

Reported expenditures for wood energy are lower than expenditures for the fossil fuels they replace. This is due largely to the unpaid time many residential users devote to collecting their own fuelwood and the moderate raw material prices they pay. In addition, much industrial wood energy consumption involves use of inexpensive wood wastes and byproducts for fuel. As a consequence, the costs of conventional fuels displaced by wood fuels are larger in terms of sales than the total spending (sales) associated with using wood for energy. The regional economic impact from wood energy is, therefore, negative if only direct and indirect sales impacts are considered (table 12). The loss to the region is estimated to be more than $200 million for both 1985 and 1995 by this measure.

However, because wood fuels tend to displace imported fossil fuels and more of the spending associated with wood energy remains within the region, the net regional economic impact is positive by other economic measures. Including the induced impact, total regional sales associated with wood energy are estimated to be over $74 million in 1985 and close to $105 million in 1995. Total regional employment associated with wood energy is projected to grow modestly, about 1 percent annually, from about 9,000 employees to more than 10,600 in 1995. Total personal income is projected to grow at a higher rate over this period, from just over $150 million to nearly $180 million.

These estimates include impacts from residential fossil fuel savings which are assumed to be spent in the typical pattern of personal consumption expenditures. Similar savings for commercial and industrial users exist, but are not incorporated because such savings are more difficult to trace and model. Thus, the estimates are conservative and may well understate the net economic benefits from fuelwood use in the Lake States region.

**Outdoor Recreation**

Recreation in the forested areas of the region was associated with $4.2 billion of direct, indirect, and induced regional sales in 1985 (table 13). This level of sales generated $1.1 billion in personal income,

based on a Type III personal income multiplier. Using a Type III multiplier, over 85,000 jobs appear to be associated with the forested area's 1985 outdoor recreation. Perhaps more significantly, between 25 and 35 percent of total recreation impacts are due to nonresidents (table 14), representing new dollars and economic activity for the region.

Much of the value associated with outdoor recreation is not priced by organized markets. Therefore, economic impacts reflect only a fraction of the value placed by society upon use of the forest resources for recreation.

### Summary of Findings

The total economic contribution to the three-state region of the three alternative forest resource uses, as measured in sales, employment, and personal income are presented in table 15. The total impacts shown are based on IMPLAN's Type III multipliers which include an estimate of the induced effect. Both resident and nonresident recreation are included and 1995 recreation impacts are conservatively assumed to be equal to those in 1985. Both direct and total average annual wage or salary (personal income per job) associated with the three forest resource uses are also shown. In addition, the average annual rate of forest product sales, employment, and personal income growth is contrasted with all manufacturing in the region for the period 1985 to 1995.

## LIMITATIONS OF METHODOLOGY

Any forecast is subject to error because of data deficiencies and unforeseen changes in technology, markets, or other factors. For example, recent energy price swings have dramatically altered wood energy forecasts and can be expected to play a role in outdoor recreation participation as well. Increasing nonwildland recreational opportunities can substitute for those on wildlands. Interest rates can greatly influence levels of economic activity in the construction industry and, in turn, demands for lumber and other wood materials. Governmental policies may also deviate from those assumed in forecasts and thus change the future course of economic activity. Given these variables and their uncertain future, this report's estimates must be considered tentative and used with caution. They reflect a synthesis of the most recent available data used by the region's state governments and the USDA Forest Service for public policy analysis and planning, but it should be noted that they apply only to the particular forest resource use definitions used in this report.

All forecasts rely to some extent on historical trends that may or may not be replicated in the future. The base year for this analysis is 1982 which was a recessionary year. Some of the estimated growth in the forest industries and the economy in general stems from recovery out of depressed economic conditions. This can be seen in table 4 by contrasting the annual growth rates between 1982 and 1985 with growth rates for 1985 to 1995. For most sectors, the 1982 to 1985 period has the higher annual growth. Additionally, although it is not indicated in the table, most sectors are assumed to experience greater growth between 1985 to 1990 than between 1990 and 1995.

## DISCUSSION

This report described the growing economic importance of Upper Lake State forests. The forests are valuable assets in the region's economy even if we focus only on outputs priced by organized markets. Their significance is growing and has the potential to grow beyond current projected trends through more intensive management, better marketing arrangements, and promotion.

Estimating final demands is, perhaps, the most critical aspect of this analysis. In general, between 1985 and 1995, timber supply in the Upper Lake States will not be the critical factor determining growth in the forest products industries, demand for forest products will be. There are a few exceptions to this. The region is the center of a dynamic structural particleboard (waferboard and oriented strand board) industry. Competition for supplies of individual timber species, especially aspen, has become intense in certain localities within the region and could constrain forest industry growth in those areas. Timber supplies are generally adequate, however. Another example of the influence of the region's timber supplies is that, as harvests approach or reach allowable cut levels in the South and Northwest, more forest product firms may consider expansion in the Upper Lake States.

Timber product demand, both inside and outside the region, is the overriding growth determinant and will continue to be so. Advances in technology will lessen dependence on particular species and expand the economic timber supply. Michigan, Minnesota, and Wisconsin have benefited from this process. Hardwoods, which dominate the total regional forest

resource, are frequently used in processes that formerly used only softwoods. Expansion in substitution possibilities can be expected to continue, but greater utilization of the region's vast timber resources will not occur unless demands exist for the products manufactured from those resources.

It should be recognized that USDA Forest Service projections of timber growth quantify only physical supply, not economic supply. Economic supply will nearly always be less than physical supply because of constraints on availability relating to such factors as stumpage prices, physical accessibility, pressure from competing uses, government withdrawals of forest land, and diverse ownership goals. Economic supply of timber was not investigated in this study. Use of a demand-driven input-output model assumes that additional inputs of every type are available at constant relative prices. Expansion of industrial capacity must always be based on an investigation of economic supply of timber within economic distance of feasible locations for new facilities.

Can the region's forests maintain higher levels of both timber harvests and recreational use? This appears to be more an issue of perception rather than physical capacity. Creative planning and management will be needed to realize potential increases in both timber production and recreational use from the Upper Lake States forests without increasing conflicts between forest users. For example, Michigan's state forest system is managed on a key-value basis. The central idea is to separate three major classes of uses and users to the degree necessary to prevent serious and unnecessary conflicts. These classes are areas managed primarily for naturalistic values, areas managed primarily for developed recreation (including motorized forms), and areas managed primarily for intensive vegetation management (for wildlife habitat and timber growth and harvest). Designation of these classes involves specifying primary and secondary purposes of management for designated areas. Areas where no conflict is foreseen remain in a mixed-use zone. The effect of this system is to concentrate efforts on areas most productive for particular purposes, and consequently to require less area for given levels of each major forest output.

Based on USDA Forest Service data, it appears that the region as a whole has sufficient forest resources to meet forecasted demands for wood products, wood energy, and forest recreation. Relative to the available resources, there appears to be deficiencies in final demands (in real terms) for many forest products. Therefore, prospects for increased economic activity in the forest product sectors are largely dependent on increases in final demands. This finding suggests a need for more detailed economic impact analysis and marketing research that can lead to increased and more effective marketing efforts on the part of the forest products industry.

Data limitations and the transitional status of the USDA Forest Service's IMPLAN model prohibit making extensive public policy recommendations here. More emphasis needs to be placed on estimating final demands and marketing analysis. These analyses should be conducted with a clear recognition of the international interdependencies in the timber market and many other sectors of the regional economy. They require a high degree of cooperation from the private sector to produce meaningful results for both government and commercial interests. More detailed consideration of import/export relations could identify import substitution prospects through greater regional production of forest products. Other research needs include detailed examination of supply constraints, cost factors, and effects on employment from changes in forest industry productivity. Another issue that should be evaluated is the impact of government policy towards the forests in terms of subsequent distributional income, tax, and employment effects.

Although the Lake States forests account for modest amounts of economic activity in the region as a whole, they are significant components of the economic base of rural areas. In this age of extreme economic distress in rural areas, caused largely by a severe downturn in the region's agricultural and mining sectors, further development of the region's forests as economic assets on which to base increased economic activity can help alleviate economic distress. It is necessary, however, to diversify the regional economy in ways that will lead to growth. Sectors targeted for emphasis must be selected on the basis of their expected future performance and expected regional comparative advantage, and not simply on their past performance.

This study took advantage of a wide range of data and models to construct a picture of the economic contribution the Lake States forests make to the region. The study particularly relied upon DRI and REMI estimates for forest products, Employment Research Associates' wood energy analysis, and

Minnesota DNR outdoor recreation data. The analysis would have been severely constrained had these sources of information not been available. Efforts aimed at conducting similar analyses for state or substate regions may well suffer from an absence of secondary information sources; however, some data and models comparable to those used in this study are likely to be available from the USDA Forest Service, state-level Commerce or Natural Resource Departments, and universities. Chappelle *et al.* (1986) provides an example of a state-level forest products industry I/O analysis.

Based on the projections presented in this report, it appears that the region's forest product industries will expand at a rate approaching 3 percent annually between 1985 and 1995. This is above the forecasted performance of the overall economy of the Lake States. Wood furniture appears to have the best growth prospects among the major groupings of forest products at the SIC 2-digit level. Starting from a relatively small base, the structural particleboard sector (SIC 2492) is projected to continue its rapid growth through the 1985 to 1995 period with an average annual growth rate of more than 8 percent. Other sectors that were projected to grow by more than 3 percent included the aggregated hardwood dimension and flooring and special product sawmills sector, pulp and paper mills, and paper coating and glazing.

This study provides the basis for an important Lake States agenda for the future. In conducting the study, we noted many data deficiencies, particularly with respect to outdoor recreation. Higher quality, compatible and consistent data on recreation needs to be developed so that economic impacts relating to recreation can be evaluated on the same basis as are those for the forest products industry.

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## APPENDIX A

### Interpretation of Impact Estimates

The personal income impact estimates for the logging camps and contractors sector will be used to illustrate how to interpret economic impact estimates (tables 4 through 11). The personal income direct impact component for this sector is estimated to be 0.198, the indirect to be 0.109, and the induced to be 0.068 (table 8). This implies that for every dollar change in final demand for this sector, 19.8 cents goes directly to personal income. Additional personal income equal to 10.9 cents is generated by intermediate transactions required to meet the final demand, and 6.8 cents in personal income is generated through additional household (induced) spending. Thus, for every $1 million change in final demand for logging camps and contractors there would be $198,000 in direct personal income, $109,000 in indirect personal income, and $68,000 in induced personal income. The Type I multiplier is the sum of the direct and indirect impacts, divided by the direct impact. For the logging camps and contractors sector, the Type I personal income multiplier can be derived as follows:

$$0.198 + 0.109 = 0.307$$
$$0.307/0.198 = 1.552$$

The Type III multiplier is calculated similarly by adding the induced impact to the direct and indirect impacts, and then dividing by the direct impact. It would be derived for the logging camps and contractors sector (with rounding) as follows:

$$0.198 + 0.109 + 0.068 = 0.375$$
$$0.375/0.198 = 1.897$$

These multipliers are used with the direct impacts to estimate the "ripple effect" from initial changes in economic activity. For example, with a $1 million change in final demands for the logging camps and contractors sector, the Type I multiplier indicates there will be 1.897 x $198,000 = $307,296 in direct and indirect personal income generated, whereas the Type III multiplier indicates there will be 1.897 x $198,000 = $375,606 direct, indirect, and induced personal income generated.

The Type I and Type III multipliers are useful as measures of the additional activity which can be expected to occur throughout the economy from changes in a particular economic sector if additional inputs are available. Because they are ratios of total impacts to the direct impact, use of the Type I and III multipliers can be misleading if used by themselves. For example, sanitary paper products has the largest Type I and III personal income and employment multipliers (tables 7 and 8). This, however, is partly a result of the low direct impacts associated with this sector.

The size of impacts differs depending on the economic measure considered and whether the induced component of the impact is included. For example, particleboard has a higher than average Type I sales multiplier, 1.54, but its Type III sales multiplier, 1.79, is lower than average for lumber and wood products (SIC 24) (table 6). As another example, the particleboard total personal income and employment multipliers can be misleading if the sector's lower than average direct impacts are not considered (tables 7 and 8).

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Table 1.—*Standard Industry Classification (SIC) codes, SIC forest industry sectors, and Lake States forest industry sectors used in this study*

| SIC code | SIC forest industry sectors | Lake States forest industry sectors |
|---|---|---|
| 2411 | Logging camps & contractors | Logging camps & contractors |
| 2421 | Sawmills & planing mills | Sawmills & planing mills |
| 2426 | Hardwood dimension flooring | Dimension flooring & special product sawmills |
| 2429 | Special product sawmills[1] | |
| 2431 | Millwork | Millwork |
| 2434 | Wood kitchen cabinets | Wood & lumber products[1] |
| 2441 | Nailed & lock corner boxes | |
| 2448 | Wood pallets & skids | |
| 2449 | Wood containers[1] | |
| 2491 | Wood preserving | |
| 2499 | Wood products[1] | |
| 2435 | Hardwood veneer & plywood | Veneer, plywood, structural members |
| 2436 | Softwood veneer & plywood | |
| 2439 | Structural wood members | |
| 2451 | Mobile homes | Prefabricated buildings and mobile homes |
| 2452 | Prefabricated wood buildings | |
| 2491 | Particleboard | Particleboard |
| 2511 | Nonupholstered furniture | Household wood furniture |
| 2512 | Upholstered wood furniture | |
| 2517 | Wood TV, radio, phone... | Other wood furniture |
| 2521 | Wood office furniture | |
| 2531 | Public bldg. & related furniture | |
| 2541 | Wood partitions, shelving... | |
| 2611 | Pulpmills | Pulpmills |
| 2621 | Paper mills | Paper mills |
| 2631 | Paperboard mills | Paperboard mills |
| 2641 | Paper coating & glazing | Paper coating & glazing |
| 2642 | Envelopes | Miscellaneous converted pulp & paper products |
| 2643 | Bags | |
| 2645 | Die-cut paper, paperboard... | |
| 2646 | Pressed & molded pulp goods | |
| 2648 | Stationery, tablets, related... | |
| 2649 | Converted paper & paperboard[1] | |
| 2661 | Building paper | Building paper |
| 2647 | Sanitary paper products | Sanitary paper products |
| 265 | Paperboard containers & boxes | Paperboard containers & boxes |

[1]Not elsewhere classified.

Table 2.—*Distribution of a recreational expenditure dollar among sectors for all recreationists and nonresident recreationists, Lake States, 1985-1986*

| SIC code | Major outdoor recreation spending categories /sectors | Average spending all recreationists | Average spending, nonresident |
|---|---|---|---|
| 20 & 21 | Food & tobacco products | 0.12 | 0.06 |
| 22 & 23 | Textiles & apparel | .02 | .03 |
| 29 | Petroleum production | .12 | .14 |
| 38 & 29 | Misc. manufacturing | .03 | .03 |
| 50 & 51 | Wholesale trade | .06 | .05 |
| 52 - 59 | Retain trade | .13 | .12 |
| 70 | Hotels & lodging places | .21 | .22 |
| 71 - 90 | Misc. services | .04 | .06 |
| 58 | Restaurants & bars | .16 | .16 |
| 79 | Amusement & recreation services | .04 | .05 |
| | Other | .07 | .08 |
| | Total | 1.00 | 1.00 |

Source: Derived from the Minnesota 1985-1986 DNR Outdoor Recreation and Expenditure Survey and the summer 1978 Motor Vehicle Visitor Survey (converted to 1982 values by sector-specific inflators from the USDA Forest Service IMPLAN Analysis Guide (1985).

Table 3.—*IMPLAN estimates of sales, employment, and personal income by forest product sector, Lake States, 1982*

| Forest sector name | Sales | Employment | Personal income |
|---|---|---|---|
| | *$million* | *Thousand jobs* | *$million* |
| **Lumber & wood products—SIC 24** | | | |
| Logging camps & contractors | 411.0 | 3.2 | 81.4 |
| Sawmills & planing mills | 244.0 | 4.7 | 68.3 |
| Hardwood dimension flooring, special product sawmills | 65.0 | 1.9 | 22.2 |
| Millwork | 680.0 | 11.0 | 139.3 |
| Wood & lumber products[1] | 710.2 | 13.7 | 196.1 |
| Veneer, plywood, structural members | 226.9 | 3.7 | 55.9 |
| Prefabricated buildings & mobile homes | 287.2 | 4.1 | 59.1 |
| Particleboard | 84.0 | 0.8 | 16.2 |
| SIC 24 total | 2,708.3 | 43.1 | 638.5 |
| **Wood furniture & fixtures—part SIC 25** | | | |
| Household wood furniture | 346.2 | 6.6 | 111.1 |
| Other wood furniture | 984.0 | 17.7 | 307.0 |
| SIC 25 total | 1,330.2 | 24.3 | 418.1 |
| **Pulp & paper products—SIC 26** | | | |
| Pulpmills | 51.1 | 0.7 | 11.8 |
| Paper mills | 4,263.9 | 31.3 | 1,013.0 |
| Paperboard mills | 1,056.6 | 7.5 | 242.4 |
| Paper coating & glazing | 1,593.5 | 15.2 | 357.6 |
| Miscellaneous converted pulp & paper products | 876.2 | 10.8 | 217.2 |
| Sanitary paper products | 1,827.4 | 6.5 | 261.4 |
| Paperboard containers & boxes | 1,598.9 | 12.7 | 342.0 |
| SIC 26 total | 11,267.6 | 84.4 | 2,445.4 |
| Total all forest product sectors | 15,306.1 | 152.1 | 3,502.0 |
| Percent of region's total manufacturing | 8.0 | 9.1 | 7.7 |

[1] Not elsewhere classified

Table 4.—*Estimated forest product sales and growth in sales, Lake States, 1982, 1985, and 1995*

| Forest product sector | Estimated sales 1985 | Estimated sales 1995 | Growth ratios 1982-1985 | Growth ratios 1985-1995 | Annual growth rate 1982-1985 | Annual growth rate 1985-1995 |
|---|---|---|---|---|---|---|
| | *1982 $million* | | | | *Percent* | |
| | **Lumber & wood products—SIC 24** | | | | | |
| Logging camps & contractors | 472 | 619 | 1.15 | 1.31 | 4.75 | 2.74 |
| Sawmills & planing mills | 294 | 375 | 1.20 | 1.28 | 6.38 | 2.47 |
| Dimension flooring & special product sawmills | 75 | 106 | 1.16 | 1.41 | 4.95 | 3.49 |
| Millwork | 815 | 1,015 | 1.20 | 1.24 | 6.24 | 2.21 |
| Wood & lumber products | 899 | 1,131 | 1.27 | 1.26 | 8.16 | 2.33 |
| Veneer, plywood, structural members | 260 | 319 | 1.14 | 1.23 | 4.58 | 2.09 |
| Prefabricated buildings & mobile homes | 454 | 590 | 1.58 | 1.30 | 16.45 | 2.66 |
| Particleboard | 185 | 406 | 2.20 | 2.20 | 30.03 | 8.19 |
| SIC 24 total[1] | 3,454 | 4,561 | 1.28 | 1.32 | 8.44 | 2.82 |
| | **Wood furniture & fixtures—SIC 25** | | | | | |
| Household furniture | 429 | 664 | 1.24 | 1.55 | 7.45 | 4.46 |
| Other wood furniture | 926 | 1,338 | .94 | 1.44 | -2.00 | 3.74 |
| SIC 25 total[1] | 1,355 | 2,002 | 1.02 | 1.48 | .63 | 3.98 |
| | **Pulp & paper products—SIC 26** | | | | | |
| Pulpmills | 52 | 72 | 1.02 | 1.37 | .77 | 3.19 |
| Paper mills | 4,526 | 6,244 | 1.06 | 1.38 | 2.01 | 3.27 |
| Paperboard mills | 1,136 | 1,430 | 1.08 | 1.26 | 2.44 | 2.33 |
| Paper coating & glazing | 1,782 | 2,462 | 1.12 | 1.38 | 3.81 | 3.28 |
| Miscellaneous converted pulp & paper products | 933 | 1,211 | 1.06 | 1.30 | 2.12 | 2.64 |
| Sanitary paper products | 1,729 | 1,915 | .95 | 1.11 | -1.82 | 1.02 |
| Paperboard containers & boxes | 1,800 | 2,273 | 1.13 | 1.26 | 4.02 | 2.36 |
| SIC 26 total[1] | 11,958 | 15,607 | 1.06 | 1.31 | 2.01 | 2.70 |
| Total all forest product sectors[1] | 16,767 | 22,170 | 1.10 | 1.32 | 3.09 | 2.83 |
| Region's total economy | | | 1.15 | 1.27 | 4.77 | 2.35 |

[1]Total forest product sector and regional growth ratios and growth rates are sales weighted averages.

Table 5.—*Estimated forest product employment and personal income, 1985 and 1995, and IMPLAN employment and personal income coefficients, Lake States*

| Forest industry sector | Employment 1985 | Employment 1995 | Personal income 1985 | Personal income 1995 | Employment coefficient | Personal income coefficient |
|---|---|---|---|---|---|---|
| | *Number of jobs* | | *1982 $million* | | *Number of jobs per $million in sales* | *Personal income per $1 in sales* |
| **Lumber & wood products—SIC 24** | | | | | | |
| Logging camps & contractors | 3,625 | 4,749 | 94 | 123 | 7.6747 | 0.1980 |
| Sawmills & planing mills | 5,621 | 7,174 | 82 | 105 | 19.1331 | .2798 |
| Dimension flooring & special product sawmills | 2,140 | 3,016 | 26 | 36 | 28.476 | .3420 |
| Millwork | 13,171 | 16,396 | 167 | 208 | 16.151 | .2049 |
| Wood & lumber products[1] | 17,335 | 21,817 | 248 | 312 | 19.294 | .2762 |
| Veneer, plywood, structural members | 4,208 | 5,173 | 64 | 79 | 16.2146 | .2465 |
| Prefabricated buildings & mobile homes | 6,504 | 8,459 | 93 | 121 | 14.3404 | .2058 |
| Particleboard | 1,719 | 3,779 | 36 | 78 | 9.3046 | .1933 |
| SIC 24 total | 54,323 | 70,563 | 810 | 1,062 | | |
| **Wood furniture & fixtures—part SIC 25** | | | | | | |
| Household wood furniture | 8,134 | 12,584 | 138 | 213 | 18.9419 | .3209 |
| Other wood furniture | 16,673 | 24,079 | 289 | 417 | 18.0009 | .3120 |
| SIC 25 total | 24,807 | 36,663 | 427 | 630 | | |
| **Pulp & paper products—SIC 26** | | | | | | |
| Pulpmills | 726 | 993 | 12 | 17 | 13.8807 | .2307 |
| Paper mills | 33,247 | 45,870 | 1,075 | 1,484 | 7.3464 | .2376 |
| Paperboard mills | 8,117 | 10,222 | 261 | 328 | 7.1463 | .2294 |
| Paper coating & glazing | 16,985 | 23,451 | 400 | 552 | 9.5255 | .2244 |
| Miscellaneous converted pulp & paper products | 11,500 | 14,930 | 231 | 300 | 12.3254 | .2478 |
| Sanitary paper products | 6,192 | 6,855 | 247 | 274 | 3.5805 | .143 |
| Paperboard containers & boxes | 14,295 | 18,056 | 385 | 486 | 7.9428 | .2139 |
| SIC 26 total | 91,062 | 120,377 | 2,611 | 3,441 | | |
| Total all forest product sectors | 170,192 | 227,603 | 3,848 | 5,133 | | |

[1] Not elsewhere classified.

Table 6.—*IMPLAN Type I and Type III sales multipliers by forest product sector, Lake States*

| Forest industry sector | Multipliers Type I | Type III |
|---|---|---|
| **Lumber & wood products—SIC 24** | | |
| Logging camps & contractors | 1.571 | 1.808 |
| Sawmills & planing mills | 1.476 | 1.877 |
| Dimension flooring & special product sawmills | 1.375 | 1.935 |
| Millwork | 1.466 | 1.851 |
| Wood & lumber products[1] | 1.463 | 1.888 |
| Veneer, plywood, structural members | 1.470 | 1.838 |
| Prefabricated buildings & mobile homes | 1.508 | 1.871 |
| Particleboard | 1.541 | 1.793 |
| SIC 24 weighted average | 1.485 | 1.859 |
| **Wood furniture & fixtures—part SIC 25** | | |
| Household wood furniture | 1.386 | 1.801 |
| Other wood furniture | 1.443 | 1.855 |
| SIC 25 weighted average | 1.428 | 1.841 |
| **Pulp & paper products—SIC 26** | | |
| Pulpmills | 1.439 | 1.753 |
| Paper mills | 1.391 | 1.588 |
| Paperboard mills | 1.455 | 1.657 |
| Paper coating & glazing | 1.461 | 1.703 |
| Miscellaneous converted pulp & paper products | 1.471 | 1.765 |
| Sanitary paper products | 1.495 | 1.650 |
| Paperboard containers & boxes | 1.465 | 1.678 |
| SIC 26 weighted average | 1.443 | 1.648 |
| Total all forest product sectors weighted average | 1.450 | 1.714 |

[1] Not elsewhere classified.

Table 7.—*IMPLAN employment impacts expressed in number of jobs per million dollars (1982) of sales and Type I and Type III employment multipliers by forest product sector, Lake States*

| Forest industry sector | Type of impact | | | | Type of multiplier | |
|---|---|---|---|---|---|---|
| | Direct | Indirect | Induced | Total | Type I | Type II |
| | *Number of jobs per $million sales* | | | | | |
| **Lumber & wood products—SIC 24** | | | | | | |
| Logging camps & contractors | 7.675 | 6.583 | 4.098 | 18.356 | 1.858 | 2.392 |
| Sawmills & planing mills | 19.133 | 4.927 | 6.915 | 30.975 | 1.258 | 1.619 |
| Dimension flooring & special product sawmills | 28.476 | 5.156 | 9.666 | 43.297 | 1.181 | 1.521 |
| Millwork | 16.151 | 6.973 | 6.646 | 29.770 | 1.432 | 1.843 |
| Wood & lumber products[1] | 19.294 | 6.277 | 7.349 | 32.920 | 1.325 | 1.706 |
| Veneer, plywood, structural members | 16.215 | 5.866 | 6.346 | 28.427 | 1.362 | 1.753 |
| Prefabricated buildings & mobile homes | 14.340 | 7.487 | 6.273 | 28.101 | 1.522 | 1.960 |
| Particleboard | 9.305 | 5.821 | 4.347 | 19.472 | 1.626 | 2.093 |
| SIC 24 weighted average | 16.060 | 6.436 | 6.465 | 28.962 | 1.401 | 1.803 |
| **Wood furniture & fixtures—part SIC 25** | | | | | | |
| Household wood furniture | 18.942 | 5.988 | 7.165 | 32.095 | 1.316 | 1.694 |
| Other wood furniture | 18.001 | 6.758 | 7.116 | 31.874 | 1.375 | 1.771 |
| SIC 25 weighted average | 18.246 | 6.557 | 7.128 | 31.932 | 1.359 | 1.750 |
| **Pulp & paper products—SIC 26** | | | | | | |
| Pulpmills | 13.881 | 4.989 | 5.423 | 24.293 | 1.359 | 1.750 |
| Paper mills | 7.346 | 4.479 | 3.399 | 15.224 | 1.610 | 2.072 |
| Paperboard mills | 7.146 | 5.000 | 3.491 | 15.637 | 1.700 | 2.188 |
| Paper coating & glazing | 9.526 | 5.060 | 4.192 | 18.778 | 1.531 | 1.971 |
| Miscellaneous converted pulp & paper products | 12.325 | 5.298 | 5.065 | 22.688 | 1.430 | 1.841 |
| Sanitary paper products | 3.581 | 5.732 | 2.676 | 11.989 | 2.601 | 3.348 |
| Paperboard containers & boxes | 7.943 | 4.873 | 3.683 | 16.499 | 1.614 | 2.077 |
| SIC 26 weighted average | 7.307 | 4.974 | 3.530 | 15.810 | 1.681 | 2.164 |
| Total all forest product sectors weighted average | 10.384 | 5.461 | 4.554 | 20.399 | 1.526 | 1.965 |

[1] Not elsewhere classified.

Table 8.—*IMPLAN personal income impacts expressed in amount of personal income per dollar (1982) of sales and Type I and Type III personal income multipliers by forest product sector, Lake States*

| Forest industry sector | Type of impact | | | | Type of multiplier | |
|---|---|---|---|---|---|---|
| | Direct | Indirect | Induced | Total | Type I | Type III |
| | *Personal income per $1 sales* | | | | | |
| **Lumber & wood products—SIC 24** | | | | | | |
| Logging camps & contractors | 0.198 | .109 | .068 | .376 | 1.552 | 1.897 |
| Sawmills & planing mills | .280 | .104 | .115 | .499 | 1.372 | 1.784 |
| Dimension flooring & special product sawmills | .342 | .102 | .161 | .605 | 1.297 | 1.768 |
| Millwork | .205 | .140 | .111 | .456 | 1.685 | 2.226 |
| Wood & lumber products[1] | .276 | .126 | .122 | .524 | 1.455 | 1.898 |
| Veneer, plywood, structural members | .247 | .119 | .106 | .471 | 1.483 | 1.912 |
| Prefabricated buildings & mobile homes | .206 | .152 | .105 | .462 | 1.738 | 2.246 |
| Particleboard | .193 | .133 | .072 | .399 | 1.687 | 2.062 |
| SIC 24 weighted average | .236 | .127 | .108 | .472 | 1.539 | 1.995 |
| **Wood furniture & fixtures—part SIC 25** | | | | | | |
| Household wood furniture | .321 | .117 | .119 | .558 | 1.366 | 1.738 |
| Other wood furniture | .312 | .136 | .119 | .567 | 1.437 | 1.817 |
| SIC 25 weighted average | .314 | .131 | .119 | .564 | 1.418 | 1.796 |
| **Pulp & paper products—SIC 26** | | | | | | |
| Pulpmills | .231 | .111 | .090 | .433 | 1.483 | 1.875 |
| Paper mills | .238 | .102 | .057 | .396 | 1.429 | 1.667 |
| Paperboard mills | .229 | .113 | .058 | .400 | 1.491 | 1.745 |
| Paper coating & glazing | .224 | .122 | .070 | .416 | 1.542 | 1.854 |
| Miscellaneous converted pulp & paper products | .248 | .127 | .084 | .459 | 1.511 | 1.852 |
| Sanitary paper products | .143 | .139 | .045 | .326 | 1.969 | 2.281 |
| Paperboard containers & boxes | .214 | .121 | .061 | .397 | 1.567 | 1.854 |
| SIC 26 weighted average | .213 | .118 | .059 | .389 | 1.553 | 1.829 |
| Total all forest product sectors weighted average | .229 | .121 | .076 | .426 | 1.530 | 1.861 |

[1] Not elsewhere classified.

Table 9.—*Estimated sales multiplier effects from changes in final demand, by forest product sector, 1985 and 1995, Lake States*

(In 1982 $million)

| Forest industry sector | 1985 multipliers | | 1995 multipliers | |
|---|---|---|---|---|
| | Type I | Type III | Type I | Type III |
| **Lumber & wood products—SIC 24** | | | | |
| Logging camps & contractors | 741 | 853 | 972 | 1,119 |
| Sawmills & planing mills | 434 | 552 | 554 | 704 |
| Dimension flooring & special product sawmills | 103 | 145 | 146 | 205 |
| Millwork | 1,195 | 1,509 | 1,488 | 1,879 |
| Wood & lumber products[1] | 1,315 | 1,698 | 1,654 | 2,136 |
| Veneer, plywood, structural members | 382 | 478 | 469 | 586 |
| Prefabricated buildings & mobile homes | 685 | 850 | 890 | 1,104 |
| Particleboard | 285 | 332 | 626 | 728 |
| SIC 24 total | 5,140 | 6,417 | 6,799 | 8,461 |
| **Wood furniture & fixtures—part SIC 25** | | | | |
| Household wood furniture | 595 | 773 | 920 | 1,196 |
| Other wood furniture | 1,336 | 1,718 | 1,931 | 2,483 |
| SIC 25 total | 1,931 | 2,491 | 2,851 | 3,679 |
| **Pulp & paper products—SIC 26** | | | | |
| Pulpmills | 75 | 91 | 104 | 126 |
| Paper mills | 6,296 | 7,187 | 8,686 | 9,915 |
| Paperboard mills | 1,653 | 1,882 | 2,080 | 2,370 |
| Paper coating & glazing | 2,603 | 3,035 | 3,596 | 4,194 |
| Miscellaneous converted pulp & paper products | 1,373 | 1,647 | 1,782 | 2,137 |
| Sanitary paper products | 2,585 | 2,854 | 2,863 | 3,161 |
| Paperboard containers & boxes | 2,636 | 3,020 | 3,329 | 3,814 |
| SIC 26 total | 17,221 | 19,716 | 22,440 | 25,717 |
| Total all forest product sectors | 24,292 | 28,624 | 32,090 | 37,857 |

[1] Not elsewhere classified.

Table 10.—*Estimated personal income impacts and multiplier effects from changes in final demand, by forest product sector, 1985 and 1995, Lake States*

| Forest industry sector | Type of impact: Direct | Indirect | Induced | Total | Type of multiplier: Type I | Type II |
|---|---|---|---|---|---|---|
| | *1982 $million* | | | | | |
| 1985 | | | | | | |
| | **Lumber & wood products—SIC 24** | | | | | |
| Logging camps & contractors | 94 | 52 | 32 | 177 | 145 | 177 |
| Sawmills & planing mills | 82 | 31 | 34 | 147 | 113 | 147 |
| Dimension flooring & special product sawmills | 26 | 8 | 12 | 45 | 33 | 45 |
| Millwork | 167 | 114 | 90 | 372 | 281 | 372 |
| Wood & lumber products[1] | 248 | 113 | 110 | 471 | 361 | 471 |
| Veneer, plywood, structural members | 64 | 31 | 27 | 123 | 95 | 123 |
| Prefabricated buildings & mobile homes | 93 | 69 | 47 | 210 | 162 | 210 |
| Particleboard | 36 | 25 | 13 | 74 | 60 | 74 |
| SIC 24 total | 810 | 443 | 365 | 1,619 | 1,250 | 1,619 |
| | **Wood furniture & fixtures—part SIC 25** | | | | | |
| Household wood furniture | 138 | 50 | 51 | 239 | 188 | 239 |
| Other wood furniture | 289 | 126 | 110 | 525 | 415 | 525 |
| SIC 25 total | 427 | 176 | 161 | 764 | 603 | 764 |
| | **Pulp & paper products—SIC 26** | | | | | |
| Pulpmills | 12 | 6 | 5 | 22 | 18 | 22 |
| Paper mills | 1,075 | 461 | 256 | 1,792 | 1,536 | 1,792 |
| Paperboard mills | 261 | 128 | 66 | 455 | 389 | 455 |
| Paper coating & glazing | 400 | 217 | 124 | 741 | 617 | 741 |
| Miscellaneous converted pulp & paper products | 231 | 118 | 79 | 428 | 349 | 428 |
| Sanitary paper products | 247 | 240 | 77 | 564 | 487 | 564 |
| Paperboard containers & boxes | 385 | 218 | 110 | 714 | 603 | 714 |
| SIC 26 total | 2,611 | 1,388 | 717 | 4,716 | 3,999 | 4,716 |
| Total all forest product sectors | 3,848 | 2,007 | 1,243 | 7,099 | 5,852 | 7,099 |

(Table 10 continued on next page)

(Table 10 continued)

| Forest industry sector | Type of impact | | | | Type of multiplier | |
|---|---|---|---|---|---|---|
| | Direct | Indirect | Induced | Total | Type I | Type II |
| | | | *1982 $million* | | | |
| **1995** | | | | | | |
| | | **Lumber & wood products—SIC 24** | | | | |
| Logging camps & contractors | 123 | 68 | 42 | 232 | 190 | 232 |
| Sawmills & planing mills | 105 | 39 | 43 | 187 | 144 | 187 |
| Dimension flooring & special product sawmills | 36 | 11 | 17 | 64 | 47 | 64 |
| Millwork | 208 | 143 | 112 | 463 | 350 | 463 |
| Wood & lumber products[1] | 312 | 142 | 138 | 593 | 454 | 593 |
| Veneer, plywood, structural members | 79 | 38 | 34 | 150 | 117 | 150 |
| Prefabricated buildings & mobile homes | 121 | 90 | 62 | 273 | 211 | 273 |
| Particleboard | 78 | 54 | 29 | 162 | 132 | 162 |
| SIC 24 total | 1,062 | 585 | 477 | 2,124 | 1,645 | 2,124 |
| | | **Wood furniture & fixtures—part SIC 25** | | | | |
| Household wood furniture | 213 | 78 | 79 | 370 | 291 | 370 |
| Other wood furniture | 417 | 182 | 159 | 758 | 600 | 758 |
| SIC 25 total | 630 | 260 | 238 | 1,128 | 891 | 1,128 |
| | | **Pulp & paper products—SIC 26** | | | | |
| Pulpmills | 17 | 8 | 7 | 31 | 25 | 31 |
| Paper mills | 1,484 | 636 | 353 | 2,473 | 2,119 | 2,473 |
| Paperboard mills | 328 | 161 | 83 | 572 | 489 | 572 |
| Paper coating & glazing | 552 | 300 | 172 | 1,024 | 852 | 1,024 |
| Miscellaneous converted pulp & paper products | 300 | 153 | 102 | 556 | 454 | 556 |
| Sanitary paper products | 274 | 265 | 85 | 625 | 539 | 625 |
| Paperboard containers & boxes | 486 | 276 | 139 | 901 | 762 | 901 |
| SIC 26 total | 3,441 | 1,799 | 941 | 6,182 | 5,240 | 6,182 |
| Total all forest product sectors | 5,133 | 2,644 | 1,656 | 9,434 | 7,776 | 9,434 |

[1] Not elsewhere classified.

Table 11.—*Estimated employment impacts and multiplier effects from changes in final demand, by forest product sector, 1985 and 1995, Lake States*

| Forest industry sector | Type of impact | | | | Type of multiplier | |
|---|---|---|---|---|---|---|
| | Direct | Indirect | Induced | Total | Type I | Type II |
| | *Number of jobs* | | | | | |
| 1985 | | | | | | |
| | **Lumber & wood products—SIC 24** | | | | | |
| Logging camps & contractors | 3,625 | 3,107 | 1,934 | 8,666 | 6,732 | 8,666 |
| Sawmills & planing mills | 5,621 | 1,449 | 2,033 | 9,103 | 7,070 | 9,103 |
| Dimension flooring & special product sawmills | 2,140 | 387 | 725 | 3,252 | 2,527 | 3,252 |
| Millwork | 13,171 | 5,683 | 5,416 | 24,270 | 18,854 | 24,270 |
| Wood & lumber products[1] | 17,335 | 5,643 | 6,607 | 29,585 | 22,978 | 29,585 |
| Veneer, plywood, structural members | 4,208 | 1,525 | 1,650 | 7,383 | 5,733 | 7,383 |
| Prefabricated buildings & mobile homes | 6,504 | 3,399 | 2,848 | 12,751 | 9,903 | 12,751 |
| Particleboard | 1,719 | 1,077 | 804 | 3,600 | 2,796 | 3,600 |
| SIC 24 total | 54,323 | 22,270 | 22,017 | 98,610 | 76,593 | 98,610 |
| | **Wood furniture & fixtures—part SIC 25** | | | | | |
| Household wood furniture | 8,134 | 2,569 | 3,074 | 13,777 | 10,703 | 13,777 |
| Other wood furniture | 16,673 | 6,258 | 6,589 | 29,520 | 22,931 | 29,520 |
| SIC 25 total | 24,807 | 8,827 | 9,663 | 43,297 | 33,634 | 43,297 |
| | **Pulp & paper products—SIC 26** | | | | | |
| Pulpmills | 726 | 259 | 282 | 1,267 | 985 | 1,267 |
| Paper mills | 33,247 | 20,271 | 15,382 | 68,899 | 53,518 | 68,899 |
| Paperboard mills | 8,117 | 5,680 | 3,966 | 17,763 | 13,797 | 17,763 |
| Paper coating & glazing | 16,985 | 9,017 | 7,470 | 33,472 | 26,002 | 33,472 |
| Miscellaneous converted pulp & paper products | 11,500 | 4,943 | 4,726 | 21,168 | 16,443 | 21,168 |
| Sanitary paper products | 6,192 | 9,911 | 4,627 | 20,730 | 16,103 | 20,730 |
| Paperboard containers & boxes | 14,295 | 8,771 | 6,630 | 29,696 | 23,066 | 29,696 |
| SIC 26 total | 91,062 | 58,852 | 43,083 | 192,995 | 149,914 | 192,995 |
| Total for all forest product sectors | 170,192 | 89,949 | 74,763 | 334,902 | 260,141 | 334,902 |

(Table 11 continued on next page)

(Table 11 continued)

| Forest industry sector | Type of impact | | | | Type of multiplier | |
|---|---|---|---|---|---|---|
| | Direct | Indirect | Induced | Total | Type I | Type II |
| | *Number of jobs* | | | | | |
| **1995** | | | | | | |
| **Lumber & wood products—SIC 24** | | | | | | |
| Logging camps & contractors | 4,749 | 4,075 | 2,536 | 11,362 | 8,826 | 11,362 |
| Sawmills & planing mills | 7,174 | 1,848 | 2,593 | 11,616 | 9,023 | 11,616 |
| Dimension flooring & special product sawmills | 3,016 | 546 | 1,025 | 4,589 | 3,565 | 4,589 |
| Millwork | 16,396 | 7,078 | 6,745 | 30,216 | 23,471 | 30,216 |
| Wood & lumber products[1] | 21,817 | 7,099 | 8,312 | 37,232 | 28,921 | 37,232 |
| Veneer, plywood, structural members | 5,173 | 1,871 | 2,024 | 9,068 | 7,044 | 9,068 |
| Prefabricated buildings & mobile homes | 8,459 | 4,417 | 3,701 | 16,579 | 12,878 | 16,579 |
| Particleboard | 3,779 | 2,363 | 1,765 | 7,906 | 6,141 | 7,906 |
| SIC 24 total | 70,563 | 29,297 | 28,701 | 128,568 | 99,869 | 128,568 |
| **Wood furniture & fixtures—part SIC 25** | | | | | | |
| Household wood furniture | 12,584 | 3,976 | 4,757 | 21,311 | 16,553 | 21,311 |
| Other wood furniture | 21,079 | 9,042 | 9,521 | 42,648 | 33,127 | 42,648 |
| SIC 25 total | 33,633 | 13,018 | 14,278 | 63,959 | 49,680 | 63,959 |
| **Pulp & paper products—SIC 26** | | | | | | |
| Pulpmills | 993 | 359 | 390 | 1,749 | 1,359 | 1,749 |
| Paper mills | 45,870 | 27,965 | 21,220 | 95,056 | 73,836 | 95,056 |
| Paperboard mills | 10,222 | 7,150 | 4,992 | 22,361 | 17,369 | 22,361 |
| Paper coating & glazing | 23,451 | 12,458 | 10,320 | 46,230 | 35,910 | 46,230 |
| Miscellaneous converted pulp & paper products | 14,930 | 6,416 | 6,134 | 27,475 | 21,342 | 27,475 |
| Sanitary paper products | 6,855 | 10,977 | 5,125 | 22,959 | 17,834 | 22,959 |
| Paperboard containers & boxes | 18,056 | 11,076 | 8,372 | 37,502 | 29,130 | 37,502 |
| SIC 26 total | 120,377 | 76,401 | 56,553 | 253,332 | 196,780 | 253,332 |
| Total for all forest product sectors | 227,603 | 118,716 | 99,532 | 445,859 | 346,329 | 445,859 |

[1] Not elsewhere classified.

Table 12.—*Wood energy sales, employment, and personal income impacts, 1985 and 1995, Lake States*

| Impacts | 1985 | 1995 |
|---|---|---|
| Sales ('82 $million) | | |
| Direct & indirect | -207.12 | -216.75 |
| Direct, indirect & induced | 74.44 | 104.70 |
| Employment (jobs) | | |
| Direct | 6,069 | 7,041 |
| Indirect | 981 | 1,193 |
| Induced | 2,046 | 2,389 |
| Total | 9,097 | 10,623 |
| Personal income ('82 $million) | | |
| Direct | 104.67 | 123.16 |
| Indirect | 12.82 | 16.08 |
| Induced | 34.32 | 40.08 |
| Total | 151.81 | 179.32 |

Table 13.—*Estimated direct and total sales, employment, and personal income impacts by sector for all (resident and nonresident) outdoor recreation in forested areas, 1985, Lake States*

| Industry sector | Sales | | Employment | | Personal income | |
|---|---|---|---|---|---|---|
| | Direct | Total[1] | Direct | Total | Direct | Total |
| | *1982 $ million* | | *Jobs* | | *1982 $ million* | |
| Food & tobacco products | 256,798 | 519,142 | 1,311 | 4,099 | 30,353 | 80,215 |
| Textiles & apparel | 50,591 | 77,612 | 727 | 1,156 | 14,995 | 22,881 |
| Petroleum production | 322,995 | 485,365 | 381 | 2,186 | 15,407 | 56,469 |
| Misc. manufacturing | 60,624 | 100,812 | 978 | 1,617 | 20,436 | 32,328 |
| Wholesale trade | 125,090 | 204,072 | 2,198 | 3,572 | 51,537 | 75,126 |
| Retail trade | 275,369 | 530,719 | 10,663 | 14,920 | 127,992 | 201,830 |
| Hotels & lodging | 441,738 | 984,325 | 17,677 | 26,330 | 127,353 | 282,775 |
| Misc. services | 85,329 | 154,061 | 2,069 | 3,217 | 35,812 | 56,093 |
| Restaurants & bars | 326,848 | 735,049 | 11,035 | 16,721 | 94,753 | 195,978 |
| Amusement & recreational services | 85,958 | 192,476 | 3,712 | 5,566 | 28,959 | 59,847 |
| Other | 144,942 | 260,896 | 3,624 | 5,798 | 43,483 | 79,718 |
| Total | 2,176,282 | 4,244,529 | 54,375 | 85,182 | 591,080 | 1,143,260 |

[1] Multiplier impacts based on Type III multiplier.

Table 14.—*Estimated direct and total sales, employment, and personal income impacts by sector for nonresident outdoor recreation in forested areas, 1985, Lake States*[1]

| Industry sector | Output | | Employment | | Personal income | |
|---|---|---|---|---|---|---|
| | Direct | Total | Direct | Total | Direct | Total |
| | *1982 $million* | | *Jobs* | | *1982 $million* | |
| Food & tobacco products | 35,667 | 72,104 | 182 | 569 | 4,216 | 11,141 |
| Textiles & apparel | 21,648 | 33,210 | 311 | 495 | 6,416 | 9,791 |
| Petroleum production | 102,423 | 153,912 | 121 | 693 | 4,886 | 17,907 |
| Misc. manufacturing | 17,554 | 29,191 | 283 | 468 | 5,918 | 9,361 |
| Wholesale trade | 33,372 | 54,442 | 586 | 953 | 13,749 | 20,042 |
| Retail trade | 77,474 | 149,316 | 3,000 | 4,198 | 36,010 | 56,784 |
| Hotels & lodging | 131,407 | 292,814 | 5,258 | 7,832 | 37,885 | 84,119 |
| Misc. services | 39,842 | 71,936 | 966 | 1,502 | 16,722 | 26,191 |
| Restaurants & bars | 97,596 | 219,483 | 3,295 | 4,993 | 28,293 | 58,518 |
| Amusement & recreation services | 29,120 | 65,206 | 1,258 | 1,886 | 9,811 | 20,275 |
| Other | 47,390 | 85,302 | 1,185 | 1,896 | 14,217 | 26,065 |
| Total | 633,494 | 1,226,916 | 16,445 | 25,485 | 178,122 | 340,194 |

[1]Multiplier impacts based on Type III multiplier.

Table 15.—*Summary of direct and total forest-related impacts, including sales, personal income and employment; average annual wage or salary associated with forest resource uses; and constrast of rates of growth between forest product sectors and regional manufacturing, 1985 and 1995, Lake States*

| Summary sector | Output | | Employment | | Personal income | | Average annual wage or salary[1] | |
|---|---|---|---|---|---|---|---|---|
| | Direct | Total | Direct | Total | Direct | Total | Direct | Total |
| | *1982 $million* | | *1,000 jobs* | | *1982 $million* | | *1982 $thousand* | |
| **1985** | | | | | | | | |
| Forest products industry | 16,767 | 28,624 | 170.2 | 334.9 | 3,848 | 7,099 | 22.6 | 21.2 |
| Wood energy | -207 | 74 | 6.1 | 9.1 | 105 | 152 | 17.2 | 16.7 |
| Outdoor recreation | 2,176 | 4,245 | 54.4 | 85.2 | 591 | 1,143 | 10.9 | 13.4 |
| Total | 18,740 | 32,943 | 230.7 | 429.2 | 4,544 | 8,394 | 19.7 | 19.6 |
| **1995** | | | | | | | | |
| Forest products industry | 22,170 | 37,857 | 227.6 | 445.9 | 5,133 | 9,434 | 22.6 | 21.2 |
| Wood energy | -217 | 105 | 7.0 | 10.6 | 123 | 179 | 17.6 | 16.9 |
| Outdoor recreation | 2,176 | 4,245 | 54.4 | 85.2 | 591 | 1,143 | 10.9 | 13.4 |
| Total | 24,129 | 42,207 | 289.0 | 541.7 | 5,847 | 10,756 | 20.1 | 19.9 |
| **Percent rate of growth 1985-1995** | | | | | | | | |
| Forest products sector average annual rate of growth | 2.56 | 2.51 | 2.28 | 2.35 | 2.55 | 2.51 | | |
| Manufacturing rate of growth | 2.27 | 2.29 | 2.61 | 2.50 | 2.48 | 2.43 | | |

[1]Calculated by dividing personal income by employment, where employment includes full and part-time jobs. The relatively low outdoor recreation average yearly wage reflects outdoor recreation affecting sectors which have both more part-time jobs and lower employee compensation. The 1995 average yearly wages are virtually the same as 1985 because the same IMPLAN base year (1982) relationships were used to construct the estimates.



☆ U.S. GOVERNMENT PRINTING OFFICE: 1989—755-475/105

Pedersen, Larry; Chappelle, Daniel E.; Lothner, David C. 1989. **The economic impacts of Lake States forestry: an input-output study**. Gen. Tech. Rep. NC-136. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 32 p.

The report describes 1985 and 1995 levels of forest-related economic activity in the three-state area of Michigan, Minnesota, and Wisconsin, and their impacts on other economic sectors based on a regional input-output model.

KEY WORDS: Project forest-based economic activity, economic impacts of outdoor recreation, economic impacts of wood energy.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION

United States
Department of
Agriculture

Forest
Service

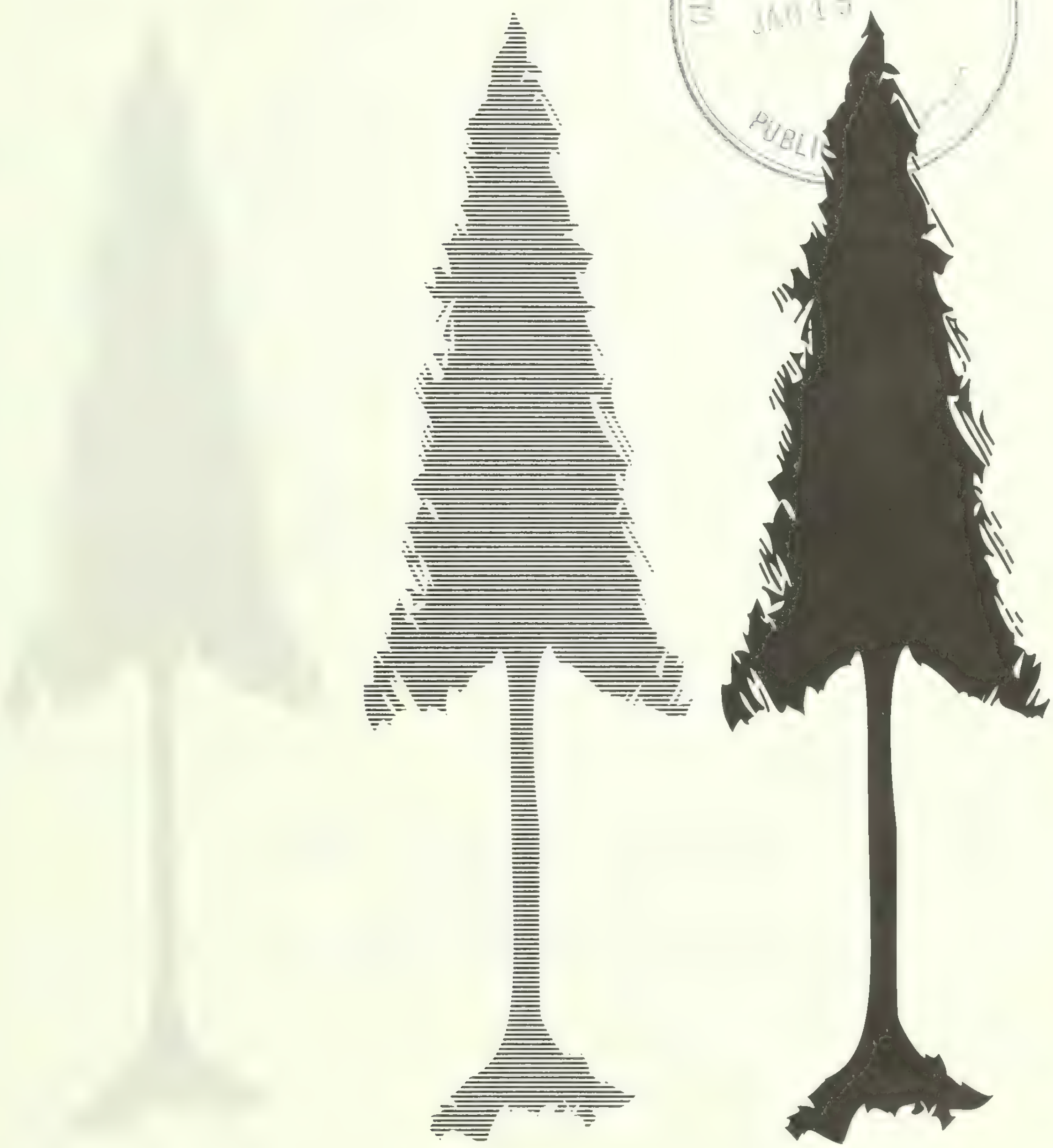
North Central
Forest Experiment
Station

General Technical
Report **NC-137**

# Identifying Emerging Issues in Forestry as a Tool for Research Planning

Hans M. Gregersen, Allan L. Lundgren, Pamela J. Jakes
and David N. Bengston





Gregersen, Hans M.; Lundgren, Allen L.; Jakes, Pamela J.; Bengston, David N.
1989. Identifying emerging issues in forestry as a tool for research planning. Gen. Tech. Rep. NC-137. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 21 p.

A Delphi exercise is used to identify emerging issues in National Forest management and use, the relative importance of the issues, and barriers to resolving issues. USDA Forest Service managers agree on the importance of the 11 issues identified; however, researchers and National Forest managers do not always agree on the importance of issues or barriers.

KEY WORDS: Research management, research evaluation, research needs, National Forest management.

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# IDENTIFYING EMERGING ISSUES IN FORESTRY AS A TOOL FOR RESEARCH PLANNING

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As with all research, it takes time for forestry research to produce results. New research initiatives can seldom offer immediate answers to the emerging critical problems faced by clients. The process by which clients, researchers, and research managers identify problems or emerging issues must be improved so that research solutions can be offered in time to make a difference—by finding either a solution to a problem or a means of changing course to avoid the problem. A case-in-point is the acid precipitation problem in the Federal Republic of Germany. Although some individuals expressed concern about the potential impacts of acid precipitation long before it became a serious problem, these warnings went unnoticed because there was no orderly process for identifying emerging problems or for alerting research managers so that action could be taken. As a result, researchers did not respond seriously to this problem until more than 15 years after the first warnings were given.[1]

Compounding the problem of identifying emerging issues is the perception of many clients that researchers set their own agendas and are not concerned with whether or not such agendas address the key problems clients face. Indeed, a concern that USDA Forest Service research does not have a central focus, and that scientists are free agents operating outside a planned research agenda, was expressed in a recent report on Forest Service research competitiveness (Chapman and Milliken 1988). We need to explore whether researchers and clients agree about the priority problems emerging in forestry. Differing perceptions of priorities would indicate a need for expanded communication between researchers and clients and for development of improved tools for consensus building.

In some cases researchers and clients agree on research priorities, but external events direct the research program. To survive, researchers may need to shift long-standing problem-solving research programs to focus on issues for which special funding has been allocated. One could argue that the Forest Service's response to the establishment of the National Acid Precipitation Assessment Program caused this type of shift in research focus (Chapman and Milliken 1988). In the case of the Forest Service, where major clients (the National Forest System and State and Private Forestry), researchers, and those allocating research funding are employed by the same organization, the question is whether different groups within the organization perceive the importance of emerging issues in a similar way. If perceptions differ, better interaction may be needed within the organization.

[1] *R. Plochmann, personal communication.*

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We conducted a study of emerging issues in forestry and barriers to addressing the issues. In this paper we provide empirical evidence on the degree of consistency between perceptions of emerging issues held by field managers and those held by researchers. We also provide information on the extent to which the views of different groups differ on barriers to resolving emerging issues. Obtaining information on emerging issues is a first step in improving communication between those who use research and those who do research.

## OBJECTIVES

The objectives of the study were to (1) develop a procedure for identifying emerging issues in forestry, and (2) conduct a case study applying the procedure to an actual situation. Our goal is to facilitate development of forestry research programs by developing a procedure for identifying emerging forestry issues.

In our case study, we applied the procedure we developed to the task of identifying emerging issues in National Forest management and use. We demonstrate here how hypotheses about differences in responses between respondent groups, geographic regions, and job tenure can be tested.

## METHOD

### The Delphi Method

A modified Delphi approach was used for achieving the study objectives. The basic Delphi "...is a group of procedures for eliciting and refining the opinions of a group of people" (Weatherman and Swenson 1974). Linstone and Turoff (1975) focus on the Delphi as "structured communication" that allows a group of individuals to deal with a complex problem. They identify seven situations or types of problems to which the Delphi is most applicable, several of which are common to natural resource management and use, including:

- problems that do not lend themselves to precise analytical techniques;
- broad or complex problems that require contributions by individuals having no history of adequate communication;
- issues where disagreements among individuals are so severe or politically unpalatable that standard communication processes are ineffective and/or anonymity of participants must be assured.

The most common Delphi process (and the one applied here) is called the Delphi exercise. In a Delphi exercise, a small team designs a questionnaire, which is sent to a respondent group. The questionnaire is returned, and the team summarizes the results. Using these results, the team designs a new questionnaire. In the second questionnaire, respondents to the first questionnaire are asked to consider the results, to change or re-evaluate their first response, and to provide further input to help focus the results. Additional rounds of questionnaires may be used until some desired level of consensus is achieved or no further consensus is thought possible.

The technique was originally developed in the 1950's at the Rand Corporation for use in studying opinions related to defense issues (Helmer 1967). Since then, many studies have used the basic approach, usually modified to fit specific study needs. Most of the modifications retain the characteristics of the Delphi exercise described above.

Variations on the basic Delphi technique also have been used quite widely in natural resource fields. For example, Shafer *et al.* (1974) used the technique to provide direction for formulating policies to deal with future environmental problems. Baughman and Ellefson (1983) used the technique to study options for county forest land in Minnesota. Schuster *et al.* (1985) applied a Delphi to a study of elk habitat quality. The technique also has been used in other countries. For example, Gunderman (1978) used a Delphi to look at standards and criteria for forest roads in the Federal Republic of Germany. Phillips *et al.* (1986)

looked at forest economics research needs for west-central Canada by using a Delphi technique for part of the study.

**Study Participants**

Because the objective of our case study was to identify issues relating to National Forest management and use, we surveyed all Forest Service Regional Foresters and Forest Supervisors, and a random sample of District Rangers (at least one per forest). We identified 60 organizations and corporations that use National Forest outputs (timber, recreation visitor days, animal unit months of grazing, acre feet of water) and included them in our study. Because the goal of identifying emerging issues is to develop timely research programs, we also sent the Delphi questionnaire to a group of researchers. Due to budget and time constraints, we included only forest economics researchers, from the Forest Service and various universities. Figure 1 indicates the numbers of individuals contacted initially in each respondent group, and the numbers participating in each stage of the study.

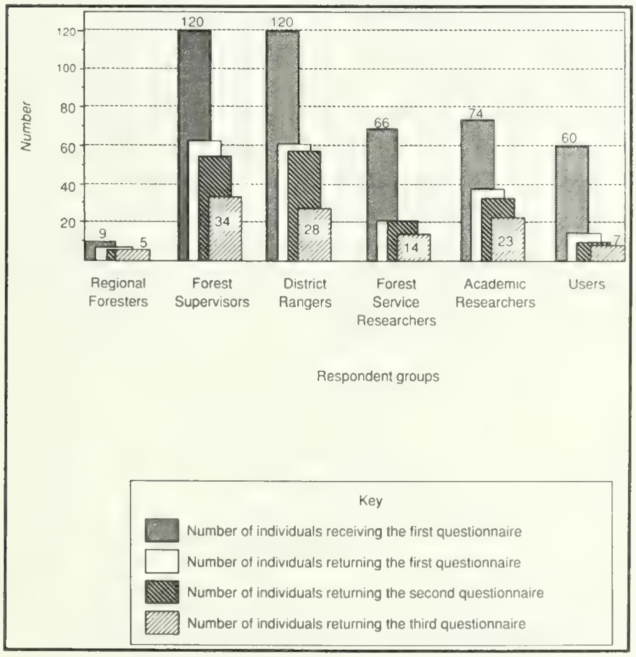


Figure 1.–*Number of respondents in each stage of the Delphi exercise by respondent groups.*

**The Delphi Exercise—Identifying Emerging Issues and Barriers**

First, we mailed an open-ended questionnaire that asked the following question:

> "From your point of view, what are the most important emerging forestry issues that National Forest managers (Rangers, Forest Supervisors, Regional Foresters) and National Forest users will face over the next 10-15 years?".

If the participant was a National Forest line manager, that person's title was entered in place of "National Forest managers (Rangers, Forest Supervisors, Regional Foresters)"—i.e. "District Rangers," "Forest Supervisors," "Regional Foresters."

Although we are ultimately concerned with developing timely research programs to address emerging issues, we did not directly ask individuals to identify research issues or needs. We were concerned that when an individual is asked to identify his or her research needs, the person is predisposed to respond in a certain way—with technical research topics dealing with genetics, forest management, forest utilization, etc. Because we were trying to identify **emerging** issues for research, we wanted to break away from the traditional responses. So, we decided to concentrate on identifying problems the individual faces in his or her job, and then leave it to the researchers and research managers to decide how research could contribute to the discussion and resolution of the issue.

Of the original 449 individuals contacted, 204 responded to the first questionnaire. The study team collated, analyzed, and synthesized these responses. Eleven major issue areas emerged from our analysis (table 1).

A second questionnaire was then prepared and mailed to all respondents. The goal of the second questionnaire was to obtain respondents' views on the relative importance of the

Table 1.—Emerging issues in National Forest management and use[1]

| |
|---|
| Increasing conflicts and polarization among various National Forest users (recreationists, hunters, loggers, etc.). [Conflicts among user groups] |
| Increasing conflicts between local and national interests and priorities. [Conflicts between local and national interests] |
| Increasing adverse impacts on the National Forests due to certain uses (e.g., off-road vehicles, marijuana growing). [Adverse impacts due to certain uses] |
| Increasing problems associated with the wildland/residential/urban interface. [Wildland/residential/urban interface] |
| Increasing role of the National Forests in watershed and water management. [Watershed and water management] |
| User fees becoming commensurate with costs (e.g., below cost timber sales, recreation). [User fees commensurate with costs] |
| Declining resources to manage the National Forests. [Declining resources] |
| Effectiveness and cost of forest planning process. [Forest planning process] |
| Inconsistencies between priorities established in the planning process and those in the budgeting/appropriations process. [Inconsistencies in priorities established during the planning and budgeting processes] |
| Increased use of legal and political processes to challenge decisions and forest plans. [Legal and political challenges to decisions] |
| Increasing constraints on planning and management activities due to environmental/conservation concerns expressed in laws or regulations (e.g., threatened and endangered species, herbicides). [Constraints imposed by laws or regulations] |

[1]Phrases in brackets indicate how issues are referenced in tables and figures.

11 major issue areas, and to have them indicate any critical issues we missed in our synthesis. We asked respondents to use a technique called magnitude scaling to indicate relative importance. Respondents assigned a number value to each issue indicating its importance relative to a reference issue, to which we arbitrarily assigned a value of 80. The participants could use any scale they wished, from 1 to 10,000 or from -100 to +100; the only stipulation was that the number given an issue indicate the importance of that issue relative to the reference issue. Two questionnaires were developed, differing in issue order and the reference issue.

Of the 204 individuals responding to the first questionnaire, 182 responded to the second questionnaire. From the responses to the second questionnaire, we were able to determine the relative importance of the 11 issues and test if there were differences in relative importance based on issue ordering on the questionnaire, respondent groups, tenure, and region.

Finally, we wanted to determine the key barriers to addressing the 11 major issues. We identified and defined for respondents four types of barriers: (1) inadequate knowledge, (2) inadequate resources, (3) inadequate incentives, and (4) inadequate institutional support (table 2). We developed a third questionnaire, which asked respondents to indicate how important the four barriers were to resolving an emerging issue. In indicating the importance of the four barriers for each issue, respondents used the following scale:

| | |
|---|---|
| 0 | not important |
| 1 | slightly important |
| 2 | moderately important |
| 3 | very important |
| 4 | critical barrier |
| NA | not applicable or no opinion |

Of the 182 participants who responded to the second questionnaire, 110 responded to the third questionnaire. Twenty-five percent of the individuals who received the first questionnaire participated in all three stages of the survey.

Table 2.—*Definitions of barriers provided to respondents on the third questionnaire*

| Barrier | Definition |
|---|---|
| Inadequate knowledge | Refers to the adequacy of technical information to deal with the issues; also related to the adequacy of our *understanding* of the economic, legal, and other elements involved in resolving the issues. |
| Inadequate resources | Relates to the adequacy of the budget of human resources in terms of applying known means of resolving the issues. |
| Inadequate incentives | Relates to the extent to which Forest Service management policies, including promotion policies and "perks," encourage action to resolve the issue; also relates to the adequacy of the incentives for user interest groups to support effective resolution of the issue. |
| Inadequate institutional support | Refers to the adequacy of the body of national and local laws and regulations that govern Forest Service activity and organization in supporting resolution of the issue being considered; it also refers to the adequacy of local and national citizen organizations that interact with Forest Service management; it refers in general to the adequacy of institutional channels for resolving issues. |

**Limitations and Considerations for Analysis**

Our goal in this study was to identify emerging issues by collecting ideas from those in the profession who think about issues and feel it is important to express their opinions when given an opportunity. Thus, we were not concerned with obtaining a representative sample from each respondent group nor are we concerned about our low response rate. Those who did respond seemed eager to express their views, and many indicated that they had been thinking about the question posed in the first questionnaire for some time. These were exactly the individuals we wanted in our panel. In a sense, a Delphi study builds in an intentional sample selectivity bias in an attempt to get at issues.

Other Delphi studies have obtained higher response rates by contacting and obtaining a commitment from potential participants before the first questionnaire. To help guarantee that we reach all interested participants, we contacted the entire population of Regional Foresters and Forest Supervisors, an unbiased sample of District Rangers, and all the researchers we could identify.

Because we were not dealing with a statistical sample, we cannot offer statistically based inferences on how the entire population of District Rangers, etc., views the issues. Rather, we were dealing with our defined population of experts, and the statements made and interpretations presented relate only to that group. The study results provide indications of emerging issues based on the opinions of a large group of people actively involved with forest management and forestry research.

In the process of consolidating and organizing the many issues raised in the first open-ended questionnaire, we risked introducing our biases or missing an important issue. We minimized this danger by stressing in the second questionnaire that respondents should write in any issues we had missed. Several additional issues were received, but none were mentioned by more than two people, and some were rewordings of one of the 11 issues. However, we

have reproduced a list of these issues in Appendix A. These additional issues should not be lost because it is often the one "voice in the wilderness" that portends the critical issue of the next decade.

## RESULTS

With the above points in mind, we discuss the questionnaire results. First, we look at results related to issues. Second, we look at results related to barriers to resolving the issues.

### Results Related to Issues

*Issue Definition*

In the first questionnaire, respondents were asked to indicate the "most important emerging forestry issues" related to National Forest management and use. Participants responded with phrases, sentences, and paragraphs. From the hundreds of pages of text, 11 issues surfaced that summarized most of the concerns raised. Phrases used below to define these issues come directly from responses to the first questionnaire. These definitions were included in the second questionnaire. The 11 issues are:

- **Increasing conflicts and polarization among various user groups (recreationists, hunters, loggers, etc.) over uses of the National Forests.** Demand is increasing for almost all uses of the National Forests. The public has an increasing interest in, and places an increasing value on, the noncommodity uses of National Forests. This implies a reduced role for the more traditional commodity outputs from National Forests. More land is being set aside for special uses, which reduces the land base available for multiple use management. Timber output is expected to decline. Special interest groups are increasingly less willing to compromise, and are becoming polarized in their viewpoints on National Forest policies. These trends pose mounting problems for National Forest management.

- **Increasing conflicts between local and national interests and priorities.** Conflicts are increasing between national and local interests and priorities, with local interests often stressing environmental and noncommodity use concerns. There is a need for national accountability, which will increasingly tie the hands of field managers. Questions related to this issue include the role of State and Federal agencies in assuring community stability. Also included are concerns over ecosystem preservation, management of old growth areas, threatened and endangered species, etc. There is also continued conflict about decentralization *vs.* centralization of authority within the Forest Service. This conflict revolves around the question of how much decisionmaking authority and responsibility should be delegated to the field. Also included here are conflicts over decisions made at different levels within the Forest Service, which may be due to a lack of adequate criteria and clear rules.

- **Increasing adverse impacts on the National Forests due to certain uses, including illegal ones (e.g., off-road vehicles, marijuana growing, etc.).** To what extent and how should National Forest uses be controlled to reduce the decline in output quality? For example, the growing use of off-road vehicles of all kinds is adversely impacting forests and related resources. The quality of recreation experiences is declining because of increased use. In some areas of the country, illegal use of National Forests for marijuana growing and drug smuggling presents difficult law enforcement problems. To what extent is improved law enforcement needed to protect public safety?

- **Increasing problems associated with the wildland/residential/urban interface.** With growing numbers of rural residences being built in wildland areas near expanding urban areas, National Forest and other wildland managers face the challenge of managing and protecting forest resources while ensuring the safety of adjacent residents and businesses. This issue also includes the problem of private landowners adjacent to National Forests who block public access to National Forests by preventing the construction of new access roads.

- **Increasing role of the National Forests in watershed and water management.** The demand for water is growing faster than the supply. In several parts of the country water will become the major concern of National Forest managers. Increasing uses of the National Forests are causing a decline in water quality. The growing concern for the improved management of riparian environments is likely to lead to increasing conflicts with range and cattle management. As demands for water use increase, western water rights will become an increasing source of conflict.

- **User fees becoming commensurate with costs (below cost timber sales, recreation, etc.).** To what extent should the costs of providing each good and service from the National Forests be recovered by user fees? What should the charges be and how should they be levied against the various uses? With declining budgets, pressure is increasing for a pay-as-you-go approach to many forest uses, particularly recreation. There is concern about the equity of fees and the potential exclusion of low-income publics from some uses if higher fees are imposed. Also included in this issue is the topic of below-cost timber sales.

- **Declining resources to manage the National Forests.** In recent years, budgets and the number of personnel have been declining on the National Forests despite increasing demands for improved management, environmental protection, and all outputs or uses. How can the National Forests be managed effectively and efficiently in the face of these trends? There is growing concern about the lack of funds to maintain public investments. Declining budgets have led to a decline in entry-level personnel, which is distorting the age-class structure of Forest Service personnel.

- **Effectiveness and cost of the forest planning process.** Concern is growing over the cost of the current forest planning process. There is a need to (1) simplify the planning process and make it more responsive to user concerns through increased public involvement, (2) improve the linkage between the planning and budgeting process, and (3) increase understanding among planners of the sophisticated planning tools and techniques they are using.

- **Inconsistencies between priorities established in the planning process and those established in the budgeting/appropriations processes.** The budget and appropriation process sets different priorities from those set in the planning process. Appropriations are often well below planned activities, and may not be in line with approved plan priorities. The Forest Service lacks decisionmaking rules and processes for implementing plans in which appropriations are not in line with approved plan priorities. Improved methods are needed for incorporating public input. Polarized user groups who are not satisfied with funded activities are likely to oppose plan implementation. Plan implementation must be monitored in relation to budget decisions.

- **Increased use of legal and political processes to challenge decisions and forest plans.** Resource professionals lack credibility with the public, and resource professionals question the public's ability to make informed, sound, and balanced decisions. There is a growing lack of acceptance of agency decisions and an increasing use of appeal processes, litigation, and political processes to change agency policies and procedures.

- **Increasing constraints on planning and management activities due to environmental/conservation concerns expressed in laws or regulations (e.g., threatened and endangered species, herbicides).** Expanding environmental concerns are placing increasing constraints on management and planning activities. Alternatives are needed for chemical pesticides and herbicides. Threatened and endangered species must be provided for, and valuable wildlife habitats must be sustained. Intensifying concern over smoke management requires alternatives to burning for slash disposal. There is increased concern about the

potential long-term cumulative effects of management activities on the environment. Disposal sites for solid toxic wastes could become an important issue. Concern is growing for maintaining or improving the long term soil/site productivity and assuring sustainable development of National Forest land. Forestry is long term, but public perception is short term.

*Importance of Each Issue*

The second questionnaire was developed to achieve consensus on the issues and to determine their relative importance. We wanted to be sure the values assigned to indicate the relative importance of issues were independent of the ordering of the issues on the questionnaire. To test if ordering affected the ratings, we prepared the "A" questionnaires with one ordering and the "B" questionnaires with issues in the reverse order. This also means that the reference issue on the "A" questionnaires became the last issue on the "B" questionnaires and vice-versa. After normalizing the values from responses to the second questionnaire, we compared the means of the values for each issue from the two questionnaires. There were no significant differences in mean values, and we concluded that the ordering did not influence values assigned. This enabled us to combine the responses from the two different questionnaires and treat them as one group.

The rankings, range in values, mean values, and standard deviations for the 11 issues are shown in table 3. Because all values were normalized around the value assigned to

Table 3.—*Range, mean values, and standard deviations for the 11 issues*

| Rank | Issue | Range | Mean | Standard deviation |
|---|---|---|---|---|
| 1 | Legal and political challenges to decisions | 19-186 | 102 | 31 |
| 2 | Conflicts among user groups | 0 | 100 | 0 |
| 3 | Conflicts between local and national interests | 25-200 | 97 | 28 |
| 4 | Inconsistencies between priorities established in planning and budgeting processes | 19-200 | 93 | 34 |
| 5 | Constraints imposed by laws or regulations | 25-178 | 92 | 28 |
| 6 | Declining resources | 13-175 | 91 | 35 |
| 7 | Forest planning process | 8-188 | 84 | 35 |
| 8 | User fees commensurate with costs | 0-185 | 82 | 33 |
| 9 | Watershed and water management | 6-150 | 78 | 33 |
| 10 | Wildland/residential/urban interface | 0-154 | 74 | 32 |
| 11 | Adverse impacts due to certain uses | 5-161 | 72 | 27 |

"conflicts among user groups," there is no standard deviation or range for that issue. If ranked by mean, the issue "legal and political challenges to decisions" ranked highest, followed closely by "conflicts among user groups" and "conflicts between local and national interests." The least important issue was "adverse impacts due to certain uses," with "wildland/residential/urban interface" and "watershed and water management" also ranking low.

Two points stand out with regard to the rankings. First, the means do not vary widely; the mean value for the lowest ranked issue is within one standard deviation of the highest ranked issue. Because the issues were developed from participant responses to the first questionnaire, it is not surprising that all 11 issues were considered important relative to the reference issue. If issues had been provided by someone other than the respondents, there probably would have been more variation. As it is, the respondents identified the important issues and, when given an opportunity, ranked them all as relatively important.

Second, the range in values (after being normalized) for each issue is large, with standard deviations near 30 for all issues. This indicates the differences in opinions about the relative importance of any one issue, even though the average or mean opinions were fairly close. As we shall see, the wide ranges in views are, in some cases, due to differences between respondent groups.

The ranking of issues would change slightly if we use the percentage of respondents ranking an issue as the most important or percentage of respondents ranking an issue as the least important as the ranking criterion (fig. 2). The issues "inconsistencies in priorities established during the planning and budgeting processes" and "declining resources" would rank higher if this criterion were used rather than mean score. On the other end, "constraints imposed by laws or regulations" would move up greatly in ranking if we used the percentage of respondents ranking an issue the least important as the criterion—this issue had the lowest "least important" rating of any issue except for our reference issue.

**Differences in Ranking Among Respondent Groups**. Respondent groups discussed below include Forest Supervisors, District Rangers, and researchers (Forest Service and academic researchers combined for most of the discussion). We combined the two researcher groups so we would have the necessary number of responses for statistical testing.

Although the response rate for Regional Foresters was the highest of any respondent group (more than 55 percent) we do not discuss their responses as a respondent group because they are so few in number. The small number meant we could not guarantee anonymity to respondents. We do not discuss responses from National Forest users for the same reason. Also, neither group had the minimum number of responses necessary for testing differences between respondent groups. And, unlike our researcher respondents, it made no sense to combine the responses into one respondent group.

There was remarkable agreement among the three respondent groups on the importance of the 11 issues, particularly with regards to the three most important and three least important issues (table 4). District Rangers and Forest Supervisors thought that "legal and political challenges to decisions and forest plans" was the number one issue, probably reflecting their

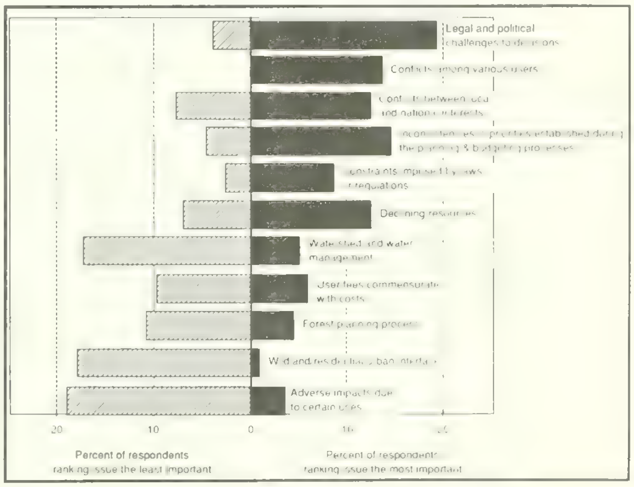


Figure 2.–*Percent of respondents ranking the issue as least important and percent of respondents ranking the issue as most important.*

Table 4.–*The three most important issues and three least important issues (using mean score as the ranking criterion) by respondent group*

| | Forest Supervisors | District Rangers | Forest Service Economics Researchers | Academic Forest Economics Researchers |
|---|---|---|---|---|
| Three highest ranked issues | • Legal and political challenges to decisions<br>• Conflicts among user groups<br>• Conflicts between local and national interests | • Legal and political challenges to decisions<br>• Conflicts among user groups<br>• Inconsistencies in priorities established during the planning and budgeting processes | • Conflicts between local and national interests<br>• Conflicts among user groups<br>• Legal and political challenges to decisions | • Declining resources<br>• Conflicts among user groups<br>• Constraints imposed by laws or regulations |
| Three lowest ranked issues | • Wildland/residential/urban interface<br>• Watershed and water management<br>• Adverse impacts due to certain uses | • Watershed and water management<br>• User fees commensurate with costs<br>• Wildland/residential/urban interface | • Wildland/residential/urban interface<br>• Watershed and water management<br>• Adverse impacts due to certain uses | • Watershed and water management<br>• Wildland/residential/urban interface<br>• Adverse impacts due to certain uses |

increasing frustration at having their management flexibility reduced. Forest Service economics researchers did not feel as strongly about this issue, ranking it third behind "conflicts between local and national interests" and "conflicts among user groups." University forest economics researchers were even less concerned with "legal and political challenges to decisions," ranking it in seventh place. They thought that "declining resources" was the most important issue in managing the National Forests. Those most affected by declining resources—Forest Service District Rangers and Forest Supervisors—were much less concerned with the issue as a constraint to management and use, ranking it fifth (table 5).

Although the mean values for the issues were similar for all respondent groups, differences are more apparent if we look at the percentage of respondents rating an issue as most important or least important. Forest Supervisors and District Rangers rated "legal and political challenges to decisions" as most important more often than any other issue—23 percent of the Forest Supervisors and 27 percent of the District Rangers rated the issue as most important (fig. 3). In contrast, only 10 percent of the researchers (Forest Service and academics combined) thought "legal and political challenges to decisions" was the most important issue. Researchers were more likely to rate "conflicts among user groups," "user fees commensurate with costs," "conflicts between local and national interests," or "constraints due to laws or regulations" as most important. Three issues—"wildland/residential/urban interface," "adverse impacts due to certain uses," and "watershed and water management"—were researchers most likely candidates for least important issue.

If we look at the number of times any one issue was given the highest rating by a respondent group, we find a significant difference between ratings given by Forest Service managers

Table 5.—*Mean score by issue and respondent group*

| | Respondent group | | | |
|---|---|---|---|---|
| Issues | Forest Supervisor | District Ranger | Researchers | All respondents |
| • Legal and political challenges to decisions | 104.1 | 111.3 | 93.3 | 103.1 |
| • Conflicts among user groups | 100.0 | 100.0 | 100.0 | 100.0 |
| • Conflicts between local and national interests | 95.3 | 98.2 | 99.3 | 97.6 |
| • Inconsistencies in priorities established during the planning and budgeting processes | 87.9 | 98.6 | 93.1 | 94.3 |
| • Constraints imposed by laws or regulations | 90.3 | 90.8 | 95.0 | 92.9 |
| • Declining resources | 87.6 | 92.2 | 94.6 | 91.5 |
| • Forest planning process | 77.2 | 83.7 | 89.6 | 84.6 |
| • User fees commensurate with costs | 77.3 | 75.8 | 92.8 | 82.4 |
| • Watershed and water management | 71.7 | 76.8 | 81.8 | 77.1 |
| • Wildland/residential/urban interface | 74.8 | 75.0 | 78.1 | 74.6 |
| • Adverse impacts due to certain uses | 69.5 | 81.1 | 70.3 | 73.0 |

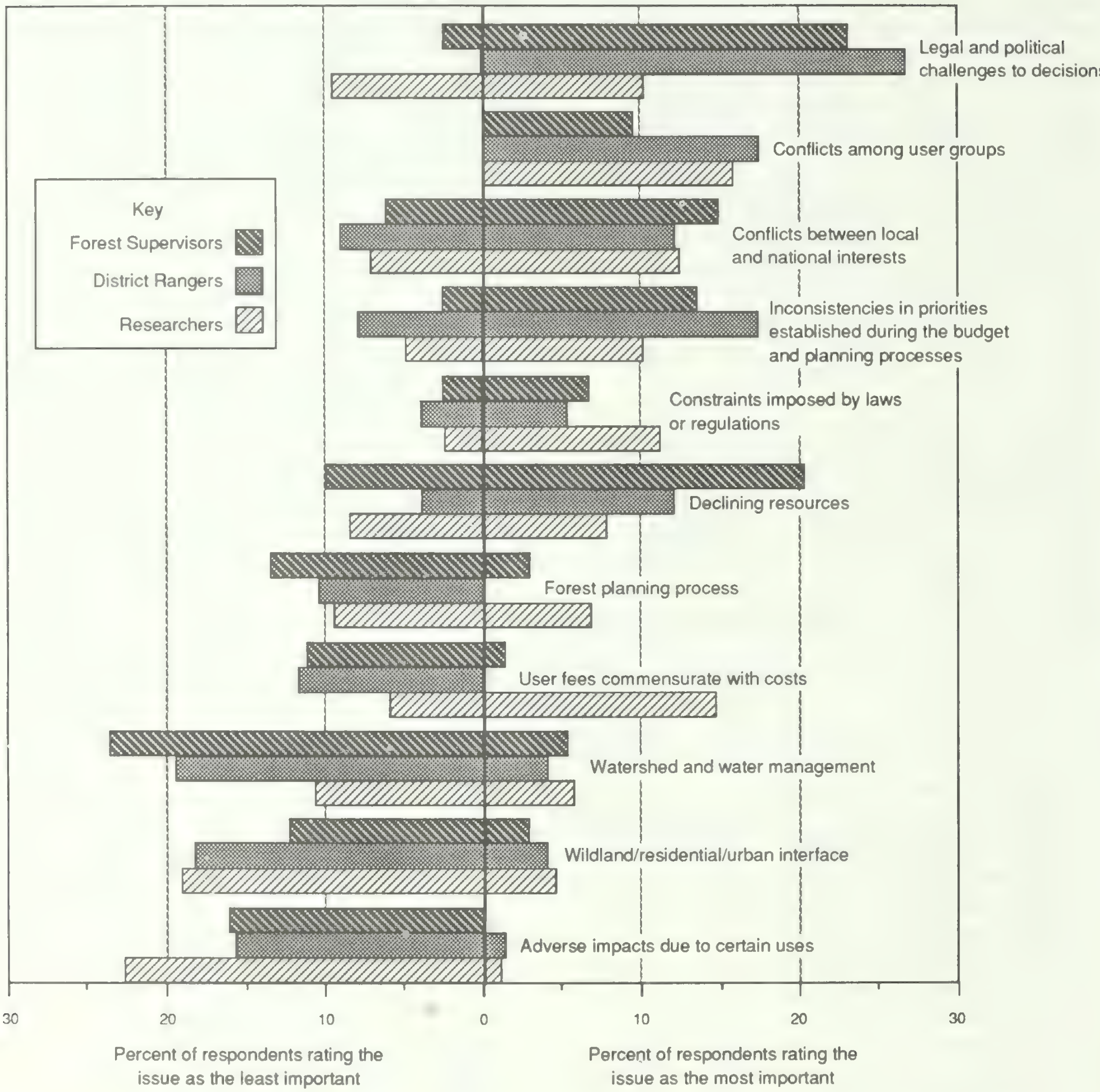


Figure 3.–*Percent of respondents ranking the issue as least important and percent of respondents ranking the issue as most important by respondent group.*

(Forest Supervisors and District Rangers) and researchers (Forest Service economics researchers and academic forest economics researchers)[2] (fig. 3). The main contributors to the difference were the issues "user fees commensurate with costs" and "legal and political challenges to decisions." "Declining resources" and "inconsistencies in priorities established during the planning and budgeting processes" also showed differences. In other words, researchers thought that "user fees commensurate with costs" was much more important than forest managers did (as indicated in figure 3), and forest managers thought that "legal and political challenges to decisions" was much more important than researchers did.

***Differences in Rankings by Length of Time in Profession or Length of Time in Current Position:*** We were interested in whether differences in the ranking given issues could be attributed to the number of years spent in the profession or length of time in their current position. For example, we hypothesized that Forest Service managers new to their profession or their position would be more likely to disagree with the ranking given issues by their peers or their superiors (i.e. Forest Supervisors) than those who had had more time to absorb the organization's values. There were no significant differences in the responses given by participants in relation to the number of years they had been in forestry or had held their current positions.

***Differences in Rankings by Geographic Region:*** The importance assigned the 11 issues confronting National Forest management and use was similar throughout the country. Although there were no significant differences in the importance of issues by geographic regions, we can make some general observations. Respondents from the North gave somewhat higher weight to "declining resources" and "increasing conflicts between national and local interests" than participants from other regions of the country. In the West, "legal and political challenges to decisions" was a more important issue than in other regions.

**Barriers to Resolving the Issue**

Respondents rated the four barriers to resolving an issue on a 4-point scale, with 0 representing no importance, 1 slightly important, 2 moderately important, 3 very important, and 4 critical. Overall, for all issues and respondents, inadequate institutional support was considered to be the most important barrier to resolving emerging issues (mean score = 2.70) (fig. 4). Inadequate knowledge was considered to be the least important barrier (mean score = 1.96). The two remaining barriers, inadequate resources and inadequate incentives, had mean scores of 2.20.

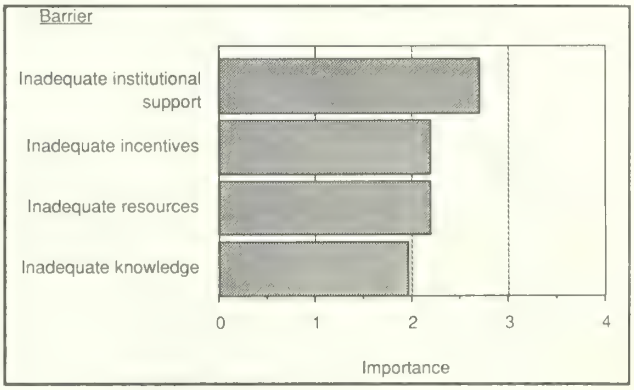


Figure 4.–*Overall importance of the four barriers to solving issues in National Forest management and use. (Importance was rated on the following scale: 0 = not important, 1 = slightly important, 2 = moderately important, 3 = very important, and 4 = critical.)*

*Barrier Rankings Among Issues*

There was a wide range in the importance given to the barriers for each issue (figs. 5). The lowest mean importance score was given to inadequate knowledge in solving issues related to declining resources—respondents did not see the need for more information to overcome the effects of declining resources on the management and use of National Forests. The highest

[2]*Differences in respondent group were tested using a Chi square test. The Chi square tests whether responses of the two groups are significantly different from that expected if the two groups were from one population. In this case, the responses were significantly different at P=0.003.*

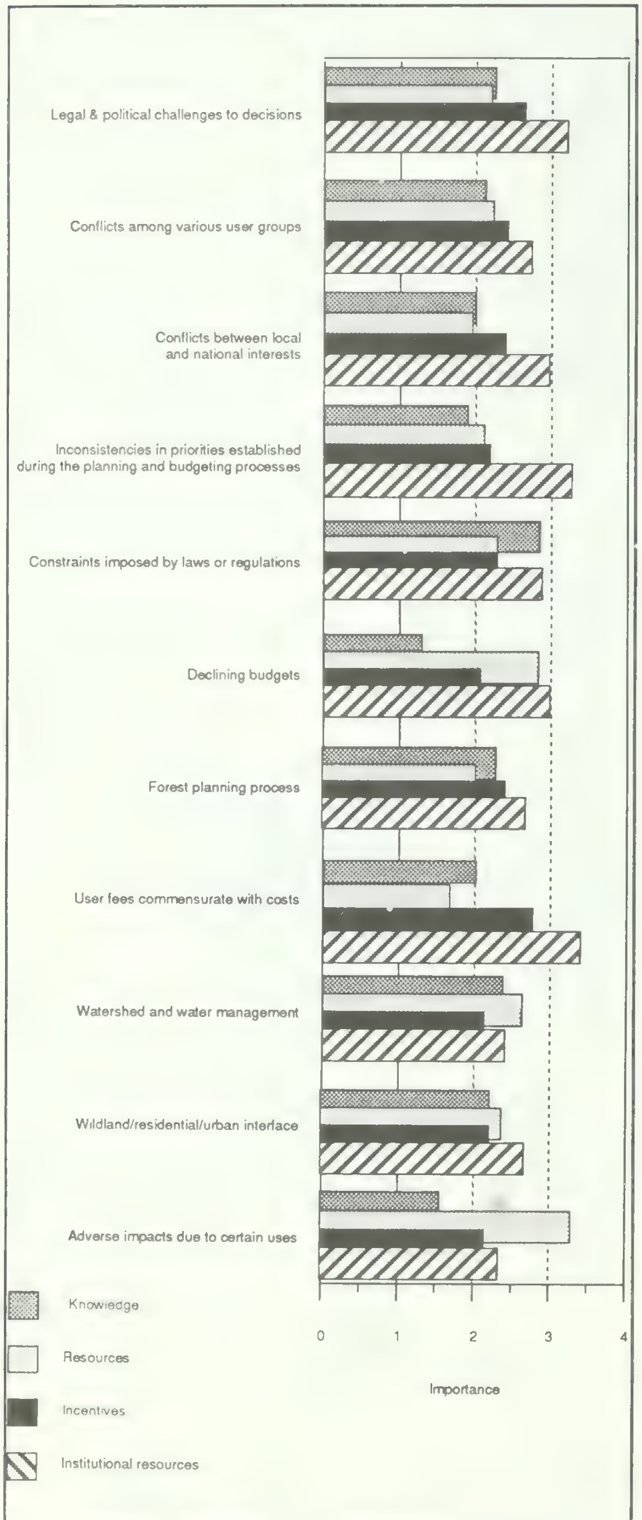


Figure 5.–*Importance of inadequate knowledge, resources, incentives, and institutional support in resolving issues related to National Forest management and use.*

mean score was given to inadequate institutional support for establishing user fees commensurate with costs—our respondents did not feel that existing laws and regulations or the organization of the Forest Service was adequate to support the establishment of user fees commensurate with costs of providing a service.

Issues hindered most by inadequate knowledge included "constraints imposed by laws or regulations," "watershed and water management," "forest planning," "legal and political challenges to decisions," and "wildland/residential/urban interface." "Adverse impacts due to certain uses" was the issue most affected by inadequate resources. Inadequate incentives was an important barrier to the issues "user fees commensurate with costs," "legal and political challenges to decisions," "forest planning," and "conflicts among user groups." Inadequate institutional support was seen as affecting "user fees commensurate with costs," "inconsistencies in priorities established during the planning and budgeting processes," and "legal and political challenges to decisions" more than other issues.

*Barrier Ranking Among Respondent Groups*

Respondent groups generally agreed on the importance of barriers to resolving the 11 issues for National Forest management and use (fig. 6), but disagreed on the importance of a barrier for a specific issue. As might be expected, researchers attached greater importance to "inadequate knowledge" than National Forest managers did, while National Forest managers saw a lack of resources as more important than researchers did.

Although there was general agreement on the importance of barriers when importance is measured as the mean score given by any respondent group, there was also considerable diversity of opinion within each group for most of the barriers and issues. We can see this if we look at the percent of respondents rating a barrier as most important and the percent rating a barrier as not important in resolving any specific issue (Appendix B). Consider, for example, the importance of inadequate incentives for resolving "inconsistencies in priorities

established during the planning and budgeting processes" (fig. 10, Appendix B). While 16 percent of the Forest Supervisors said that inadequate incentives were critical to resolving this issue, another 16 percent said this barrier was of no importance.

**DISCUSSION**

What follows are some general conclusions and suggestions for follow-up to this study.

First, we developed a method for researchers and clients to identify emerging issues in National Forest management and use, the relative importance of the issues, and barriers to resolving the issues. Once issues and barriers have been identified, it becomes the task of policy and decision makers to develop action plans for addressing issues. Where research is called for, researchers and research managers must develop research projects that offer the greatest potential for resolving the issues. The development of research studies to solve a specific problem generally cannot be aided by group interaction or consensus building. It has been shown elsewhere that researchers themselves are the major players in developing specific research projects within some broad issue areas set by funding agencies or planning mechanisms (Jakes 1988). Top-down assignment of specific research topics to good researchers is seldom productive or effective. What we have done here is identify some broad issue areas.

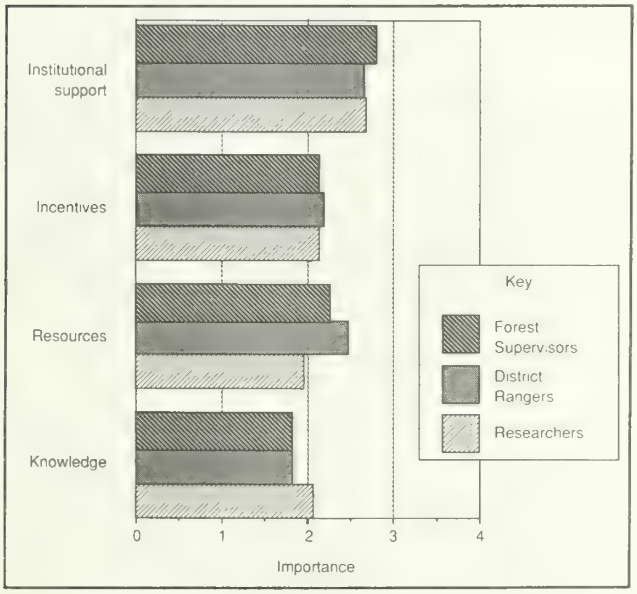


Figure 6.–*Importance of four barriers as rated by respondent groups. (Importance was rated on the following scale: 0 = not important, 1 = slightly important, 2 = moderately important, 3 = very important, and 4 = critical).*

Second, although the broad, aggregate analysis presented here is useful for identifying national issues, the diversity in response from regions and individuals should not be lost. Local priorities were different from national priorities in several instances. If this method is used to develop research priorities for a particular region, research station, or research program, all potential clients and researchers should be included so that sources for issues are not inadvertently excluded.

Third, the agreement of Forest Service managers on the importance of the 11 issues was striking. Eighty-one percent of the Forest Supervisors and 86 percent of the District Rangers responding gave the top ranking to the same five issues: "legal and political challenges to decisions," "conflicts among user groups," "conflicts between local and national interests," "inconsistencies in priorities established during the planning and budgeting processes," and "constraints imposed by laws or regulations." There was also close agreement on the importance of the four barriers in resolving issues, with institutional barriers ranked as most important.

Fourth, we have demonstrated that researchers and National Forest managers do not always agree on the importance of issues related to the management and use of National Forests, or on the potential barriers to resolving the issues. Undoubtedly, similar differences in perceptions exist between forestry researchers and other clients. The question is, are differences in perceptions important? They are if they hinder research programs to solve important resource problems. If researchers and clients do not agree on research problems, then the research

program will not be viewed as effective. We see a continued need for dialogue between researchers and their clients, particularly when defining research problems.

Finally, for many of the 11 issues, the research relevant to the issue is social science research—specifically social, behavioral, and managerial sciences. Seldom do you see social science research identified as a priority for forestry research. The traditional response to requests for research needs focuses on technical questions, such as growth and yield data, wildlife habitat requirements, and recreation user information. Research in these fields is essential to maintaining the resource base and improving production efficiency. The need for more and better technical information would have undoubtably been expressed by another group of natural resource professionals. However, our respondents have indicated that this technical information does little to resolve day-to-day issues they face as resource managers. The responses by our National Forest managers indicate how their jobs have changed since the days of Gifford Pinchot. The 11 issues reflect the realities faced by today's forest manager—they relate, almost exclusively, to people problems, not technical problems. In the first questionnaire we asked respondents to suggest any issue they felt was emerging as important—we did not exclude technical issues. In reading the responses to the first questionnaire, we sensed that we are much further ahead in terms of our technical knowledge than we are in terms of our knowledge of how to manage people and organizations. Analysis of our responses indicates a need for expanded research in fields such as law, sociology, political science, economics, and management sciences, or more development and application of research already done in those fields to forestry.

From these findings, we suggest five follow-up activities:

- Expand this present effort to bring in researchers from disciplines other than economics, and explore means for bringing National Forest users more effectively into the process.
- Explore alternative means of establishing dialogue between researchers and resource managers so management issues and research strategies can be discussed more systematically, and with differences of opinions can be recognized and discussed.
- Bring together forest economists and other social and behavioral science researchers to identify strategies for addressing the 11 issues identified here.
- Apply the approach developed here at the Forest Service Research Work Unit level, using a Delphi exercise to develop problems for the Research Work Unit Description.
- Explore possibilities for establishing a natural resources research program in conflict management.

Regarding the final recommendation, there is a significant body of scientific literature related to conflict management in other fields (see references cited in Marcouiller and Ellefson 1987). Given that 4 out of 5 of the most important issues identified by Forest Supervisors and District Rangers deal with conflict resolution, this would appear a relevant area to explore.

The method and issues developed in this study should aid in the management of research and natural resources in the Forest Service. With continued research in these areas, particularly in the follow-up areas suggested above, we can help ensure that forestry research is pro-active rather than just reactive.

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## APPENDIX A—ADDITIONAL ISSUES OFFERED ON THE SECOND QUESTIONNAIRE BY RESPONDENT GROUP

### Forest Service Manager (Forest Supervisor or District Ranger)

- Conflict between traditional goods and services produced on National Forest land and new thinking on long-term productivity.
- Current range management practices and funding.
- Public education about why we do what we do.
- Inability of the Forest Service organization (at all levels) to recognize and then manage, i.e., cope with emerging issues.
- A probable shift nationally toward import of agricultural products (to include timber) which will shift demand for National Forest resources away from traditional emphasis on timber selling and more toward other resources. Will require an adjustment in skills and attitudes within the agency.
- Increasing use of misinformation techniques to "scare" the general public into supporting nondevelopment of resources.
- Management of energy resources on National Forest system.
- Lack of salesmanship by Forest Service to take our message and show our management to users.
- Interagency coordination (State and Federal). Increasing problems associated to wetlands. Demand for information from interest groups.
- Maintaining long-term site productivity.

- Declining morale of Forest Service employees causing decrease of quality and quantity.

- Other State and Federal agencies controlling activities on National Forest land, such as minerals, threatened and endangered species, water.

- Metropolitan America does not recognize the need for wood on public land to be used for industry production of wood products.

- Effect of affirmative action directions on recruiting and holding a highly qualified and motivated work force.

- Decreasing amount of common sense in young people.

- Hiring, training, and retaining a highly efficient and motivated work force. Process of implementing forest plans. Use of prescribe fire to obtain resource objectives. Coordination with State and Federal agencies responsible for single (or limited) resources vs. the multiple resource agencies like the Forest Service.

- The inability and reluctance to get decisions implemented.

- The role of the National Forests in the nation. (Define the goods and services they are to provide in the future.) (How much wood should come from public lands?) Clearcutting and/or the silvicultural methods used to harvest timber.

**Researcher (Forest Service and Academic)**

- I still feel strongly about the problem of establishing constant resource values.

- Is the National RPA Assessment/Program consistent with forest-level planning?

- National Forests becoming National Parks.

- Plan alternative rationalization, i.e., can an agency "prefer" a 30 percent reduction in harvest or scale backs in species populations—or should legislative targets be set.

- Need to greatly increase staff and dollars on fish and wildlife commensurate with "Multiple Use Management." Better training of foresters—political system, administration, communications.

- Increasing problems due to negative externalities from private land management that impact National Forest system lands.

- Ability of universities to graduate foresters having adequate technical skills/ability to develop skills.

- I found it difficult to make clear distinctions between your issues, e.g., issues 9 and 11 seemed part of issue 2 and issues 1 and 3 seemed really the same. Also, my answers are biased. I put more weight on issues I knew something about. Some issues are oriented more toward National Forest administration problems, less toward broader policy issues (which I knew more about). The water issue will be more "western." I can't help but feel these employment and regional biases will show in response. I guess some cross-tabs will help show if my feeling is correct.

- Economic efficiency of management-fiscal and economic accountability. Economic as well as biological/technical efficiency (might be assumed under issue 8 but here more concern with management rather than planning).

- Inadequate identification of user needs and inadequate management of the Forest Service as an institution to meet these needs.

- Shift in commodity production from NF to private lands, especially NIPF.

- Develop technological and marketing strategies to utilize resources currently wasted or unused.

- Research efforts are declining while research needs, i.e., problems are increasing. Reduced attention to the recreation resource. Limited research on integrated resource management. Limited attention to

urban needs and concerns. Limited attention to the visual resource.

- Failure to recognize nonpriced values in planning and budgeting processes.

- Uncertainty in future demand for forest products, especially traditional sawtimber products. Potential for production enhancing technology, such as biotechnology advances in timber growth, and insect/disease control, and pulp/paper processing.

**Other (National Forest User)**

- Identify the economic importance of timber management to local communities.

- Decreased commitment to policy of "the greatest good to the greatest number of people."

## APPENDIX B—FIGURES SHOWING THE IMPORTANCE OF BARRIERS TO RESOLVING ISSUES BY ISSUE AND RESPONDENT GROUP

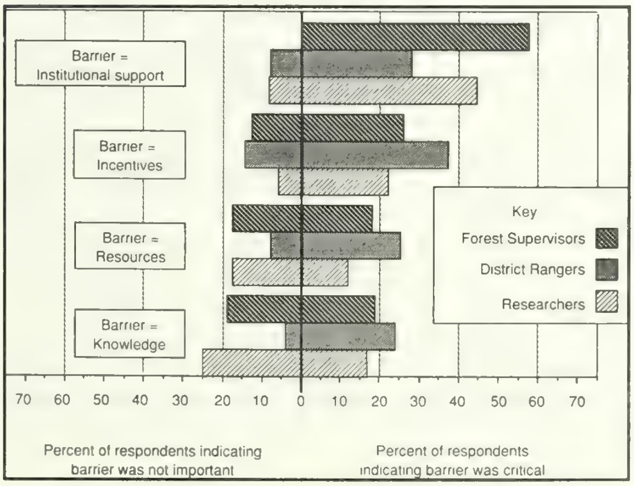


Figure 7.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving legal and political challenges to decisions, by respondent group.*

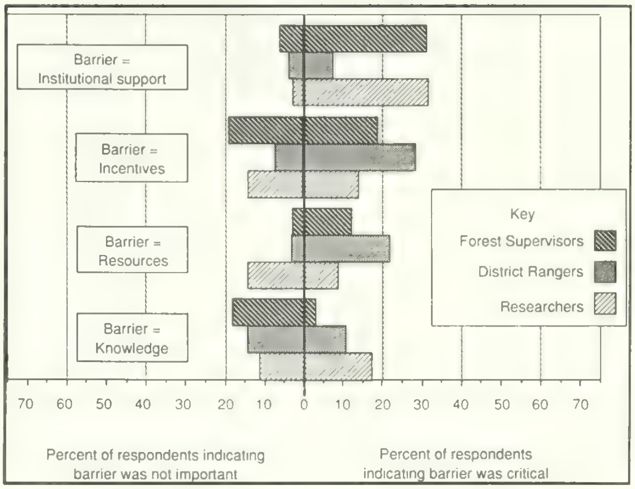


Figure 8.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving conflicts among various users, by respondent group.*

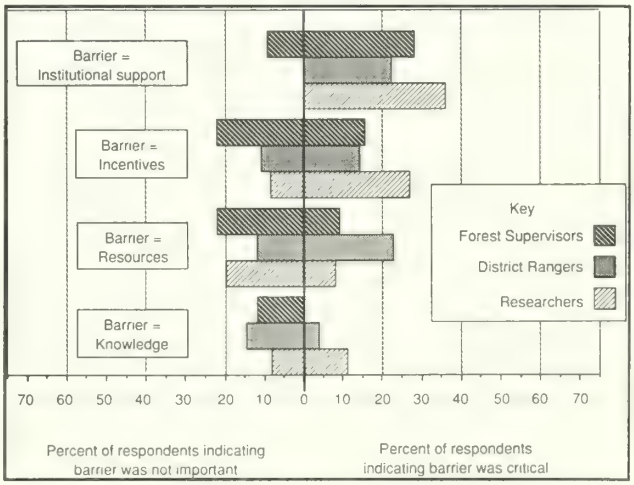


Figure 9.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving conflicts between local and national interests, by respondent group.*

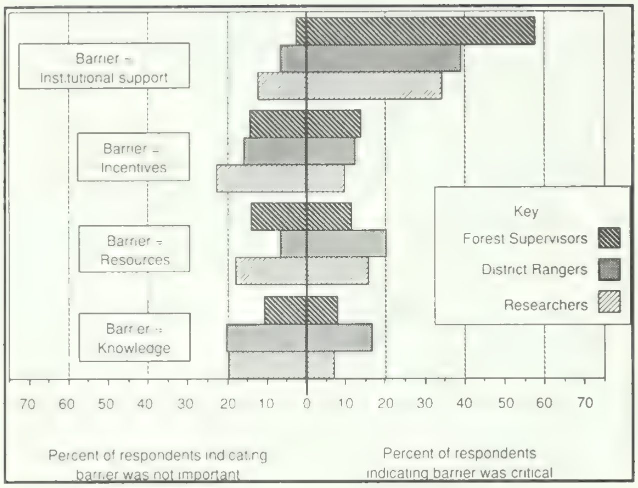


Figure 10.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving inconsistencies in priorities established during the planning and budgeting processes, by respondent group.*

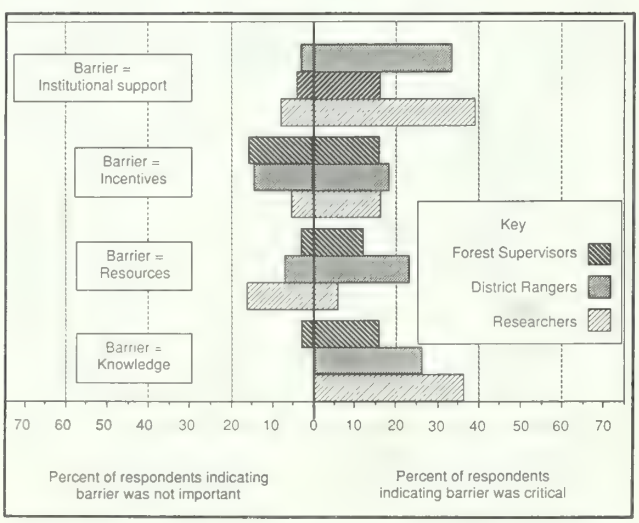


Figure 11.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving constraints imposed by laws or regulations, by respondent group.*

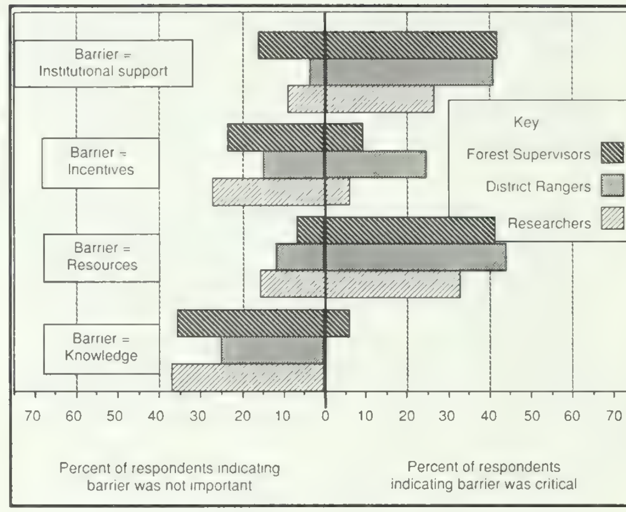


Figure 12.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving declining budgets, by respondent group.*

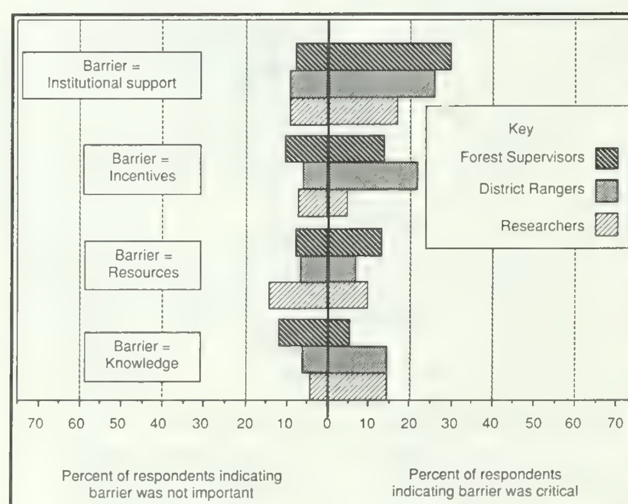


Figure 13.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving the forest planning process, by respondent group.*

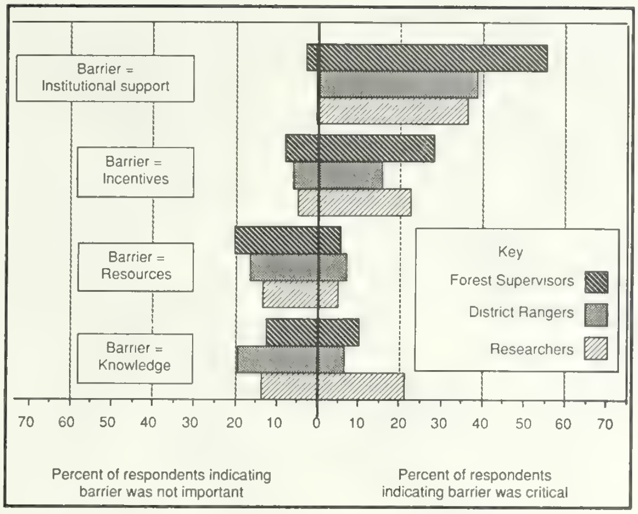


Figure 14.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving user fees commensurate with costs, by respondent group.*

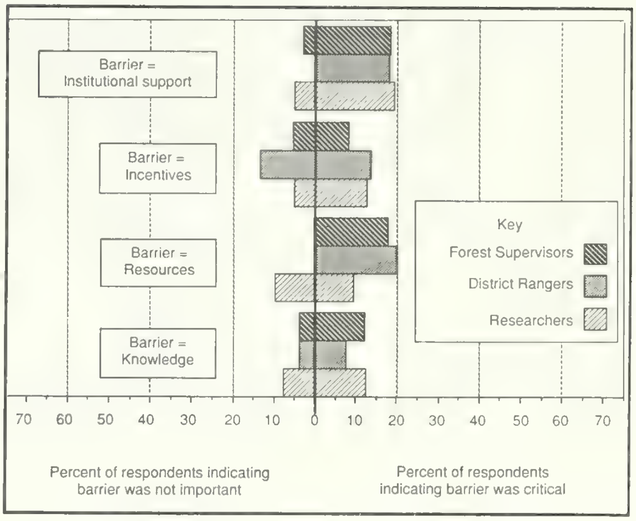


Figure 16.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving management questions related to the wildland/residential/urban interface, by respondent group.*

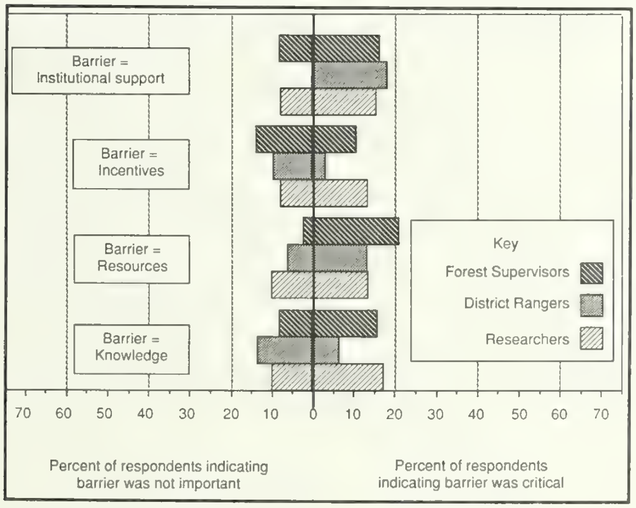


Figure 15.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving questions related to water and watershed management, by respondent group.*

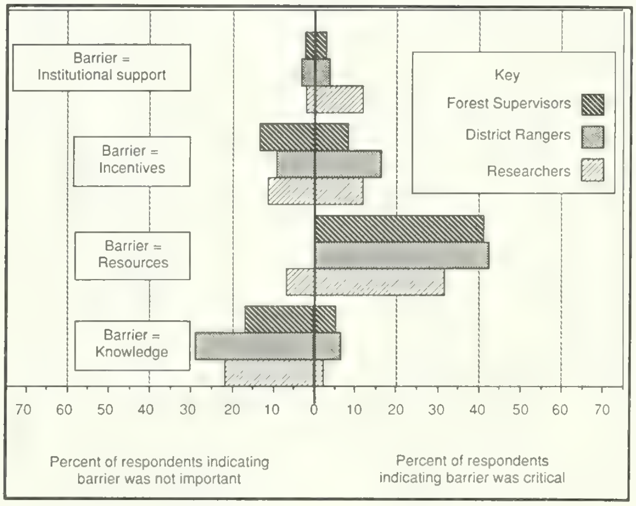


Figure 17.–*Percent of respondents indicating a barrier was not important and percent of respondents indicating a barrier was critical in resolving adverse impacts due to certain uses, by respondent group.*

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Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION

United States
Department of
Agriculture

Forest
Service

North Central
Forest Experiment
Station

General Technical
Report NC-138

# FIREFAMILY 1988

William A. Main, Donna M. Paananen, and Robert E. Burgan

## Note to the Reader

The 1988 version of the National Fire-Danger Rating System (NFDRS) will be field tested in 1990. If changes occur as a result of these tests, there may also be some changes in FIREFAMILY. We therefore advise you to watch for possible NFDRS and FIREFAMILY revisions in 1991.

North Central Forest Experiment Station
Forest Service–U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication March 15, 1990
1990

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# FIREFAMILY 1988

## William A. Main, Donna M. Paananen, and Robert E. Burgan

One of the missions of wildland fire management is to integrate fire with other land management activities to achieve desired objectives at the lowest cost. When fire managers know how fires are likely to behave in an area as well as that area's associated weather, topography, and fuel moistures, they can establish limits for public and industrial activities, plan prescriptions for burning, pre-position and dispatch suppression resources, and select appropriate wildfire suppression tactics. This publication and its predecessor (Main *et al.* 1982) show fire managers how to employ FIREFAMILY, a computer program that uses historic weather data to predict future fire management needs.

*FIREFAMILY 1988* has been revised to reflect changes resulting from the 1988 revisions to the National Fire-Danger Rating System (NFDRS) (Burgan 1988). The changes, made at the request of the fire management community in the Eastern United States, provide the following improvements:

- An increased drought response in humid environments.
- More flexibility to reflect greening and curing of live fuels.
- A better estimate of fire danger in the autumn.
- A better estimate of fire danger following precipitation.
- A new set of 20 fuel models to implement the changes.

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These changes enable fire managers either to use the system nearly unaltered from the 1978 NFDRS or to select those modifications that address their local problems.

The three major routines of FIREFAMILY are FIRDAT, SEASON, and FIRINF. In the routine FIRDAT, fire weather station characteristics are combined with daily weather records and the equations of the NFDRS to produce **frequency distributions tables** and **graphs** of the NFDRS indexes and components. These **frequency tables** and **graphs** are useful for determining manning levels. For an explanation of the NFDRS, see Deeming *et al.* (1977), Burgan *et al.* (1979), Burgan (1988), and Helfman *et al.* (1987). SEASON and FIRINF re-read data created by FIRDAT and organize it into probabilities, seasonal graphs, calendars, and other fire management tools.

In the following sections, we discuss each of these three major routines, emphasizing what you will be required to provide as well as how you can analyze the various products. We also provide an Appendix to acquaint you with the Fort Collins Computer Center (FCCC) job-control language required to operate this program. Because FIREFAMILY continually grows to meet users' needs, you might notice slight differences between the output used for illustration and that received from the Fort Collins computer. For updated instructions, contact the USDA Forest Service, Fire and Aviation Management Staff, P.O. Box 96090, Washington, DC 20090-6090.

### FIRDAT ROUTINE

FIREFAMILY has been revised to permit processing of all historical weather records in the Fire Weather Data Library with either 1978 or 1988 NFDRS fuel

models. Appendix IV provides computational details for using pre- and post-1988 style weather data with either fuel model set. Required changes in the program operation are defined in this publication.

You will begin the analysis of your data by providing information to FIRDAT on lead cards. This information includes the station's elevation, latitude, fuel model, slope class, herbaceous type, shrub type, beginning Keetch-Byram Drought Index value, beginning 1,000-hour timelag fuel moisture, average annual precipitation, and climate class (see Appendix I). FIRDAT will read this information as well as your historical weather data on file at the National Fire Weather Data Library (NFWDL) (see Furman and Brink 1975).

FIRDAT examines your weather data on a daily basis to determine the best option to use in computing the daily fuel moistures. Then, using the NFDRS equations, FIRDAT calculates the NFDRS components and indexes. These daily values of weather, indexes, and components can be saved for later use; they **must** be saved if you are going to use SEASON and/or FIRINF. You can request a printout of these values called the **daily list**.

An innovative aspect of this routine allows you to define the specific dates for a fire season for a particular protection area. This feature is especially helpful if you have a split fire season. In the Northeast, for example, fires occur frequently in both the spring and the fall, but few fires occur in the summer. You might select April 10 as the beginning of the fire season and November 9 as its end on lead card one (Appendix Ia). Then on lead card two (Appendix Ib), you would exclude the summer period from June 21 to September 11 when there are few fires. FIRDAT would then provide a frequency analysis for only the high risk spring and fall periods.

FIRDAT always prints a **summary of station statistics** for each year you select. When the data for your station end, the routine prints **frequency distributions tables** and **graphs** for those NFDRS indexes and components you chose on lead card one.

### Header Page

FIREFAMILY always prints a **header page** (fig. 1) showing the information you supplied on your lead cards. Always keep your **header page** attached to the output as a permanent record of the input you used for that run. The **header page** repeats (character-by-character) the information you supplied. The program then inspects your lead cards for consistency and format. For instance, if the weather information read by the computer is not for your station, or is outside the years that you specified on your lead card, you will receive an error message.

The large block number 240107 on our **header page** (fig. 1) is the weather station number. Bold letters **A** and **B** point out the information supplied on the FIRDAT lead cards. Letter **C** identifies a SEASON lead card and letter **D** identifies a FIRINF lead card. Note that you can provide up to three separate lead cards for both SEASON and FIRINF.

The routine prints a KEY line under the CARD line to identify the entries immediately above it.
Find ! = <u>PASSING FILE</u> on lead card one. The KEY character "!" is associated with the **passing file**, an essential FIREFAMILY component that passes FIRDAT data to SEASON and FIRINF. Now find the "!" in the KEY line. Look directly above the "!" and find a "T" **(E)**. The "T" stands for true, indicating that a **passing file** was created in this run. An "F" (false) in the CARD line would mean that the **passing file** was not created and is not available for use with SEASON and FIRINF.

### Daily List

If you choose to print the weather data, the routine will print the **daily list** (fig. 2). Always examine your **daily list** closely to ensure that the historical weather elements correspond to your original weather records.

At the top of each page, the title "DAILY LIST" appears. Included on the left are the FIREFAMILY version number—"1988 NFDRS VERSION FFY 3.0," the administrative ownership—"KOOTENAI NF," the station name and number—"LIBBY MONTANA 240107," and the user-selected MODEL-"8C," SLOPE CLASS-"2," HERB TYPE-"A," SHRUB TYPE-"E," and CLIMATE CLASS-"2." Model 8C refers to the 1988 NFDRS fuel model C. A 7C designation would refer to the 1978 NFDRS fuel model C. Included on the right are the date of the run, page number, station elevation and latitude, and the fire season dates.

Bold **A** indicates abbreviated column headings. From left to right, these abbreviations stand for: date of observations; season of the year; processing option; state of the weather; dry-bulb temperature; relative humidity; wind speed; maximums and minimums of temperature and relative humidity; amount and duration of precipitation; lightning activity level; human-caused risk; the six fuel moistures: woody and herbaceous with their associated greenness factors, 1-hour,

```
1988 NFDRS     VERSION FFY 3.0                     FIRE DANGER STATISTICS                      27  OCT.  89  PAGE     1



              2222          44      000000       11       000000    77777777
            22222222   44   44      000000      111       000000    77777777
            22     22  44   44     00    00    1111      00    00         77
                   22  44   44     00    00   11111      00    00         77
                  22   44   44     00    00      11      00    00        77
                 22    44   44     00    00      11      00    00        77
                22     44   44     00    00      11      00    00       77
               22      44444444    00    00      11      00    00       77
              22       44444444    00    00      11      00    00      77
            22              44     00    00      11      00    00      77
            22222222        44      000000    11111111    000000      77
            22222222        44      000000    11111111    000000      77

A .LEAD CARD ONE PROVIDES THE STATION DESCRIPTION AND CONTROLS FOR FIRDAT.
  .                                                                  E
CARD.1KOOTENAI NF LIBBY MONTANA       240107 2070498C2AE2F7277 5 9 9 9TTTTTTTTTTTFFT
KEY . , UNIT NAME,,    STATION NAME    ,,NMBR,,ELV,LLMMSHSC1,YR,,BGNEND,12345678FD+W!
    .ELV= ELEVATION ,'LL-MM-S-H-S-C-1= LATITUDE,MODEL,SLOPE,HERB TYPE,SHRUB TYPE,CLIMATE,1 HR = 10 HR,YR= YEARS
    .BGNEND=FIRE SEASON DATES,1-8=SELECTED FREQ DIST.,F=MOIST FREQS,D=DAILY LIST,+=NO FIRDAT,W=LIST WEATHER ONLY,!=PASSING FILE.
    .
B .LEAD CARD TWO PROVIDES ADDITIONAL CONTROLS.
  .
CARD.2 1.00 12 12 6 1 910 20.3  020  0  0  0  0  0  0  0  0   0   069097
KEY . (LRS)  W  E(GU)(FR) PPT KDITHMMSHSCMMSHSCMMSHSCMMSHSC(LOW-HI)F1%2%
    . (LRS)= LIGHTNING SCALING FCT, HUMAN RISK W= WEEKDAY, E= WEEKEND (GU)= GREENUP MONTH-DAY,(FR)= FREEZE,
    .PPT= AVERAGE ANNUAL PRECIP, KDI= STARTING KEETCH-BYRAM DROUGHT INDEX, TH=STARTING 1000 HOUR FUEL MOISTURE
    .MMSHSC= MODEL-SLOPE-HERB-SHRUB-CLIMATE, (LOW-HI)= SKIP PERIOD, F= FILL SEA & INF ARRAYS, 1%2%= MANNING PERCENTILES.
    .
C .LEAD CARD THREE MAY BE REPEATED UP TO 3 TIMES, AND PROVIDES THE CONTROL FOR SEASON.
  .
CARD.3112345670TT 5F6  0  0  0  0  0  0T  0   .0  .00
KEY . L12345678GT()YP,6 PERST DIVISNS ,B90% EXBI,EXDY
    .L= VARIABLE LIST, 1-8= SELECTED VARIABLES, G= GRAPHS, T= TABLES, ()= AVERAGING PERIOD,
    .Y= SINGLE YEARS ,P= PERSIST INDEX, B= BI SEVERITY,
    .90%= BI PERCENTILE VALUE, EXBI= AV.BI SUM, EXDY= AV.DAYS GREATER THAN 90%
    .
D .LEAD CARD FOUR MAY BE REPEATED UP TO 3 TIMES, AND PROVIDES THE CONTROL FOR FIRINF.
  .
CARD.4TF0  0  0  0  0  0  0  0  0  0  00  0  0  0  0  0  0  0  0  0  0
KEY . APX,    TEN HORIZ DIVISIONS     ,Y,     TEN VERTC DIVISIONS      .
    .A= ADJECTIVE CLASS, P= PRECAUTIONS CLASS, X= HORIZONTAL INDEX, Y= VERTICAL INDEX.
```

Figure 1.–*Header page.*

1988 NFDRS VERSION FFY 3.0 DAILY LIST 27 OCT. 89 PAGE 2
KOOTENAI NF LIBBY MONTANA 240107 ELEVATION- 2070 LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2 FIRE SEASON- 5/ 9 TO 9/ 9

| DY | S | O P | S W | D B TMP | REL HUM | WD SP | TEMP MAX | TEMP MIN | RH MAX | RH MIN | PRECIP AMNT | PRECIP DUR | LAL | HUM RSK | WOODY FM | WOODY GF | HERB FM | HERB GF | 1 HR | 10 HR | 100 HR | 1000 HR | KDI NDX | IGN COM | SPD COM | ENR COM | HOI NDX | LOI NDX | BUR NDX | FLI NDX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MAY 1972 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 1 | 1 | 62 | 23 | 3 | 64 | 19 | 99 | 20 | .00 | 0 | 1 | 12 | 60 | 0 | 5 | 0 | 5 | 10 | 15 | 20 | 2 | 11 | 2 | 14 | 1 | 0 | 13 | 9 |
| 2 | 0 | 1 | 1 | 67 | 43 | 0 | 70 | 25 | 99 | 20 | .00 | 0 | 1 | 12 | 60 | 0 | 8 | 0 | 8 | 13 | 14 | 19 | 5 | 5 | 1 | 10 | 1 | 0 | 9 | 6 |
| 3 | 0 | 1 | 1 | 60 | 55 | 0 | 70 | 26 | 66 | 22 | .00 | 0 | 1 | 12 | 60 | 0 | 10 | 0 | 10 | 14 | 12 | 19 | 8 | 4 | 1 | 9 | 0 | 0 | 8 | 6 |
| 4 | 0 | 1 | 2 | 62 | 51 | 3 | 70 | 31 | 99 | 30 | .00 | 0 | 1 | 12 | 60 | 0 | 10 | 0 | 10 | 14 | 13 | 19 | 11 | 4 | 2 | 9 | 0 | 0 | 10 | 7 |
| 5 | 0 | 1 | 2 | 62 | 43 | 0 | 70 | 41 | 99 | 40 | .00 | 0 | 1 | 12 | 60 | 0 | 9 | 0 | 9 | 13 | 14 | 18 | 14 | 4 | 1 | 10 | 0 | 0 | 9 | 6 |
| 6 | 0 | 1 | 2 | 59 | 36 | 0 | 64 | 39 | 99 | 36 | .00 | 0 | 1 | 12 | 60 | 0 | 8 | 0 | 8 | 13 | 14 | 18 | 16 | 5 | 1 | 10 | 1 | 0 | 9 | 6 |
| 7 | 0 | 1 | 2 | 60 | 50 | 0 | 66 | 37 | 99 | 30 | .00 | 0 | 1 | 12 | 60 | 0 | 10 | 0 | 10 | 14 | 14 | 18 | 18 | 3 | 1 | 9 | 0 | 0 | 8 | 6 |
| 8 | 0 | 1 | 6 | 50 | 81 | 0 | 67 | 43 | 100 | 42 | .04 | 1* | 1 | 12 | 60 | 0 | 18 | 0 | 20+ | 22 | 15 | 18 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 1 | 2 | 52 | 76 | 0 | 56 | 40 | 99 | 52 | .35 | 2* | 1 | 12 | 60 | 0 | 20 | 0 | 20 | 20 | 16 | 18 | 2 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 0 |
| [illegible] | 0 | 1 | 3 | 59 | [illegible] | [illegible] | [illegible] | [illegible] | 99 | 52 | .00 | 0 | 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 15 | 15 | 16 | 18 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2 | 87 | 30 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 2 | 15 | 2 | 0 | [illegible] | [illegible] |
| 30 | [illegible] | [illegible] | [illegible] | 91 | 26 | 0 | 93 | 42 | 99 | [illegible] | [illegible] | [illegible] | [illegible] | 12 | 60 | 0 | 5 | 0 | [illegible] | [illegible] | [illegible] | [illegible] | 100 | 13 | 1 | 16 | 2 | 0 | 12 | 9 |
| 31 | 0 | 1 | 9 | 75 | 63 | 3 | 85 | 49 | 99 | 32 | .10 | 1* | 1 | 12 | 60 | 0 | 12 | 0 | 12 | 14 | 13 | 16 | 109 | 3 | 1 | 7 | 0 | 0 | 9 | 6 |
| 31 | | | | | | | | | | | .82 | 9 | | 372 | | | | | | | | | 1218 | 192 | 44 | 301 | 22 | 0 | 304 | 216 |
| JUNE 1972 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 0 | 1 | 1 | 79 | 27 | 4 | 82 | 44 | 99 | 27 | .29 | 2* | 1 | 12 | 65 | 0 | 17 | 0 | 9 | 9 | 14 | 16 | 97 | 6 | 2 | 12 | 1 | 0 | 12 | 9 |
| 2 | 0 | 1 | 1 | 82 | 19 | 3 | 82 | 36 | 99 | 19 | .00 | 0 | 1 | 12 | 69 | 0 | 24 | 0 | 8 | 8 | 13 | 15 | 104 | 7 | 2 | 13 | 1 | 0 | 12 | 9 |
| 3 | 0 | 1 | 1 | 76 | 36 | 1 | 80 | 46 | 99 | 22 | .00 | 0 | 1 | 12 | 73 | 0 | 30 | 0 | 7 | 11 | 13 | 15 | 110 | 7 | 1 | 12 | 1 | 0 | 10 | 7 |
| 4 | 0 | 1 | 1 | 78 | 26 | 2 | 80 | 36 | 99 | 26 | .00 | 0 | 1 | 12 | 77 | 0 | 36 | 0 | 5 | 9 | 13 | 15 | 116 | 11 | 1 | 14 | 1 | 0 | 12 | 9 |
| 5 | 0 | 1 | 0 | 85 | 27 | 4 | 87 | 37 | 99 | 18 | .00 | 0 | 1 | 12 | 81 | 0 | 43 | 0 | 5 | 9 | 13 | 15 | 125 | 13 | 2 | 14 | 2 | 0 | 13 | 9 |
| 6 | 0 | 1 | 0 | 91 | 18 | 3 | 93 | 37 | 99 | 12 | .00 | 0 | 1 | 12 | 85 | 0 | 49 | 0 | 4 | 7 | 12 | 15 | 137 | 15 | 2 | 16 | 2 | 0 | 13 | 9 |
| 7 | 0 | 1 | 3 | 76 | 46 | 5 | 81 | 54 | 99 | 38 | .00 | 0 | 1 | 12 | 88 | 0 | 58 | 0 | 9 | 12 | 13 | 15 | 143 | 5 | 1 | 8 | 1 | 0 | 9 | 6 |
| 8 | 0 | 1 | 3 | 75 | 63 | 3 | 75 | 56 | 99 | 48 | .16 | 1* | 1 | 12 | 92 | 0 | 67 | 0 | 14 | 14 | 14 | 15 | 146 | 1 | 1 | 3 | 0 | 0 | 4 | 3 |
| 9 | 0 | 1 | 2 | 71 | 73 | 2 | 78 | 57 | 99 | 48 | .20 | 1* | 1 | 12 | 97 | 0 | 76 | 0 | 16 | 16 | 14 | 15 | 135 | 0 | 0 | 2 | 0 | 0 | 2 | 1 |
| 10 | 0 | 1 | 9 | 80 | 33 | 3 | 82 | 56 | 99 | 22 | .45 | 2* | 1 | 12 | 102 | 0 | 81 | 0 | 9 | 9 | 14 | 15 | 97 | 3 | 1 | 7 | 0 | 0 | 7 | 5 |
| 11 | 0 | 1 | 3 | 47 | 93 | 0 | 60 | 44 | 99 | 42 | .55 | 3* | 1 | 12 | 109 | 0 | 96 | 0 | 30 | 30 | 16 | 16 | 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

( * = DURATION OR 10HR MOISTURE WAS CALCULATED. T = TRACE OF PRECIP. + = RAINING AT OBS TIME.)

Figure 2.–*Daily list.*

10-hour, 100-hour, and 1,000-hour; the Keetch-Byram Drought Index; three NFDRS components: ignition, spread, and energy release; four NFDRS indexes: human-caused fire occurrence, lightning-caused fire occurrence, burning, and fire load. Because this example illustrates processing of 1978 NFDRS weather data with a 1988 NFDRS fuel model, season and greenness factor data are not available, so these values are defaulted to 0.

Three special symbols may appear in the printout. A star "★" **(B)** after either the precipitation duration or the 10-hour fuel moisture indicates that these values were computed rather than read from the data. A plus sign "+" **(C)** after the 1-hour fuel moisture shows that it was raining at observation time. A "T" after a zero ".00" in precipitation amount would indicate a trace. A key to this information appears at the bottom of each **daily list** page.

At the end of each month, FIRDAT produces a summary report **(D)** of the number of days in the month, the precipitation amount and duration, and the human-caused risk level. The NFDRS indexes and components are also totaled. This report may be used to chart the monthly progress of your fire season. The **daily list** also provides a convenient way to learn how changing weather elements affect the fuel moistures and the NFDRS values. It is a complete statement of all that is known from a fire-danger point of view about any particular day, and it can provide information for fire reviews, trespass cases, arson investigations, and other studies when no other measurements were made.

In addition, fire managers who study the **daily list** might also see sudden changes in the character of a particular element such as woody fuel moisture green-up. Note that before green-up on June 1 **(E)**, the woody fuel moisture was held constant, and the herbaceous fuel moisture was the same as the 1-hour fuel moisture. At green-up, the living fuel moistures begin to increase.

### Summary of Station Statistics

The **summary of station statistics** (fig. 3) is printed after each year is processed. The usual heading appears at the top of the page with the title. The year **(A)** for which these data are being summarized is printed below the title. This printout summarizes the lightning fire occurrence indexes for the fire season **(B)** using a lightning scaling factor **(C)** specified on lead card two. The summary also illustrates the pattern of lightning activity level distribution **(D)**. These statistics are required to recalculate the lightning scaling factor for use with the AFFIRMS program. (See Appendix D of Deeming *et al.* 1977 for a discussion of this analysis.) FIRDAT reports how much data were missing from the official fire season **(E)** and the total number of days processed **(F)**.

The average ignition component is printed to help the fire manager appraise the local adjustment for human-caused fires **(G)**. (See Deeming *et al.* 1977, Appendix E.) If you have selected the **passing file** (a product of FIRDAT that passes data to SEASON and FIRINF), the total number of records written on it will be noted at the bottom of the final annual summary that you receive **(H)**.

### Frequency Distributions Table

FIRDAT sorts all the days in a station's fire season from the lowest to the most extreme fire danger and prints out a **frequency distributions table** (fig. 4). On lead card one you select the indexes, components, and/or fuel moistures for tabulation. You will receive a table for each variable that you select. The table summarizes how often each level of that measure of fire danger occurred.

In our example, the burning index **(A)** was the chosen variable. Our table shows the total number of days (743) that fell within the fire season **(B)** and the total number of classes (14) into which the variable is divided **(C)**. To ensure that this table will fit on one page, FIRDAT limits the number of classes to 50. In our example, the BI could range from 0 to 100, so the routine automatically chose a step size of two **(D)**. The sequence is detailed in the upper boundary column.

The first column of this table shows class (or row) numbers. The first row of the table (CLASS NO. 1) gives the number of days with a BI of zero. (When it is raining, fire weather observers enter zero values in their weather logs.) In this example, because the step size is 2, the second row (or CLASS NO. 2) includes days that had burning indexes of 1 and 2 with an upper boundary of 2 **(E)**. The next column **(F)** tells how many days were at those levels of the BI. The relative frequency column **(G)** indicates that the 44 days in row two make up 5.9 percent of the total number of days.

Many agencies use the cumulative frequency **(H)** as the basis for determining their adjective levels or manning classes. Cumulative frequency is the percent of all the days in the fire season that had as small a

```
1988 NFDRS     VERSION FFY 3.0                    SUMMARY OF STATION STATISTICS                    27  OCT.  89  PAGE    36
KOOTENAI NF    LIBBY MONTANA          240107                                               ELEVATION- 2070  LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2                              FIRE SEASON- 5/ 9 TO  9/ 9


                                            1977 A


          T O T A L  OF LIGHTNING OCCURRENCE INDEXES  FOR THE FIRE SEASON OF  5/ 9 -  9/ 9 LESS    0-   0  IS --  191 B
                                     WITH A LIGHTNING SCALING FACTOR OF  1.00 C

     .........................................................................................................
                         LIGHTNING ACTIVITY LEVEL DISTRIBUTION

       LAL      NO IN   PCT
      CLASS     CLASS   FREQ              FREQUENCY DISTRIBUTION

        1         56     45       *********************************************
        2         51     41       *****************************************
        3         12     10       *********
        4          4      3       ***                   D
        5          1      1       *
        6          0      0

     .........................................................................................................
                                    W E A T H E R   O B S   S C O R E

                         YOU RECORDED WEATHER FOR A TOTAL OF 124 OUT OF A POSSIBLE 124 DAYS
                          DURING YOUR DEFINED FIRE SEASON.  YOU L O S T    0 PERCENT OF YOUR DATA E

                            A TOTAL OF  214 DAYS WERE PROCESSED IN AND OUT OF THE FIRE SEASON. F


     .........................................................................................................

                        AVERAGE IGNITION COMPONENT FOR THE DEFINED FIRE SEASON IS --  7 G
     .........................................................................................................

                     AT THIS POINT IN THE RUN  1113 RECORDS HAVE BEEN WRITTEN TO THE PASSING FILE. H
```

Figure 3.–*Summary of station statistics.*

1988 NFDRS VERSION FFY 3.0 FREQUENCY DISTRIBUTIONS 27 OCT. 89 PAGE 47
KOOTENAI NF LIBBY MONTANA 240107 ELEVATION- 2070 LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2 FIRE SEASON- 5/ 9 TO 9/ 9

BURNING INDEX **A** TOTAL NO OF DAYS 743 **B** NO OF CLASSES 14 **C** STEP SIZE 2 **D**

90.%= 14.56 **I**
97.%= 17.46

| CLASS NO. | UPPER BOUNDARY **E** | FREQUENCY **F** | RELATIVE FREQ **G** | CUMULATIVE FREQ **H** |
|---|---|---|---|---|
| 1 | 0 | 82 | 11.0 | 11.0 |
| 2 | 2 | 44 | 5.9 | 17.0 |
| 3 | 4 | 45 | 6.1 | 23.0 |
| 4 | 6 | 75 | 10.1 | 33.1 |
| 5 | 8 | 130 | 17.5 | 50.6 |
| 6 | 10 | 102 | 13.7 | 64.3 |
| 7 | 12 | 102 | 13.7 | 78.1 |
| 8 | 14 | 76 | 10.2 | 88.3 |
| 9 | 16 | 45 | 6.1 | 94.3 |
| 10 | 18 | 27 | 3.6 | 98.0 |
| 11 | 20 | 8 | 1.1 | 99.1 |
| 12 | 22 | 3 | .4 | 99.5 |
| 13 | 24 | 2 | .3 | 99.7 |
| 14 | 26 | 2 | .3 | 100.0 |

Figure 4.–*Frequency distributions table.*

value as the one indicated in the upper boundary column. In row two, for example, 17.0 percent of the 743 days in the fire season had burning indexes of 2 or less. Often, fire managers determine their manning levels at two specific percentile values. You can specify these two values on lead card two. FIRDAT will use 90th and 97th percentiles **(I)** unless you enter different ones. Our example indicates that the BI has a value of 15 (14.56, rounded up), or less, 90 percent of the time in the fire season. Similarly, the fire manager would expect the BI to be 17 (17.46, rounded down) at least 97 percent of the time. On the other 3 percent of the days, the burning index will exceed 17.

### Frequency Distributions Graph

The points on the **frequency distributions graph** (fig. 5) are the cumulative frequencies listed in the last column of the **frequency distributions table** (fig. 4). This graph allows you to find the cumulative percentage of days in your fire season that any value of the chosen variable exceeds. In our example, the vertical line drawn at the 50th percentile **(A)** intersects the **frequency distributions graph** near the BI of 8. Thus, on half of the days in the fire season, the BI will be approximately 8 or less.

### Manning Class Table

Frequency distributions are often used to determine agency manning classes. One method for calculating the upper boundaries for six manning classes is shown in table 1[1]. We used our **frequency distributions table** (fig. 4, **I**) to find the upper boundaries for the 90th and 97th percentiles of the BI. Then we divided the 90th percentile value (15) according to the formulas shown to obtain the upper boundaries of the other classes. Remember that the lower boundary of the lowest range is 0, but the upper boundary of the extreme range is limited only by the index or component selected.

### Observed Weather Elements

FIREFAMILY allows you to request a printout of **observed weather elements** (fig. 6). (Note: choosing this feature will suppress all other FIREFAMILY features.) The column headings **(A)** are similar to those in the daily list, except that no fire-danger rating values are calculated or printed. This is the only FIREFAMILY listing that shows how the relative humidity was measured **(B)**. In our example, RH indicates that the relative humidity was measured directly rather than estimated from a wet-bulb or a dew point temperature. This printout is also the only one that shows the wind direction **(C)**.

### FIRDAT Lead Card One

The information that the fire manager provides on the lead cards is vital to the success of FIREFAMILY routines. Every time FIREFAMILY is run, you must provide lead cards one and two. The options you choose will determine the results obtained as well as the costs of running the program.

Lead card one (Appendix Ia) already has been coded with a 1 in the first card column. Continue by coding with the administrative owner's name, station name and number, elevation in feet, and latitude. For example, KOOTENAI NF; LIBBY MONTANA; 240107; 2070 feet; and 49° were coded in card columns 2-46.

[1] *See Appendix E of the AFFIRMS manual (Helfman* et al. *1987) for an example of a 10-manning class table.*

Table 1.–An example of a 6-manning class table

| Manning class | Description | Burning index | Calculation formulas | Upper boundaries of manning classes |
|---|---|---|---|---|
| 6 | Extreme | 18+ | Above the 97th percentile | (100+) |
| 5 | Very high | 16-17 | 97th percentile (from table) | 17 |
| 4 | High | 12-15 | 90th percentile (from table) | 15 |
| 3 | High moderate | 8-11 | 90th percentile/1.33 = 10.95 | 11 |
| 2 | Low moderate | 5-7 | 90th percentile/2 = 7.28 | 7 |
| 1 | Low | 0-4 | 90th percentile/4 = 3.64 | 4 |

NOTE: The lower boundary in each manning class is one more than the upper boundary of the next lowest class. Set the upper boundary of the extreme class high enough to accommodate the most extreme value of your variable.

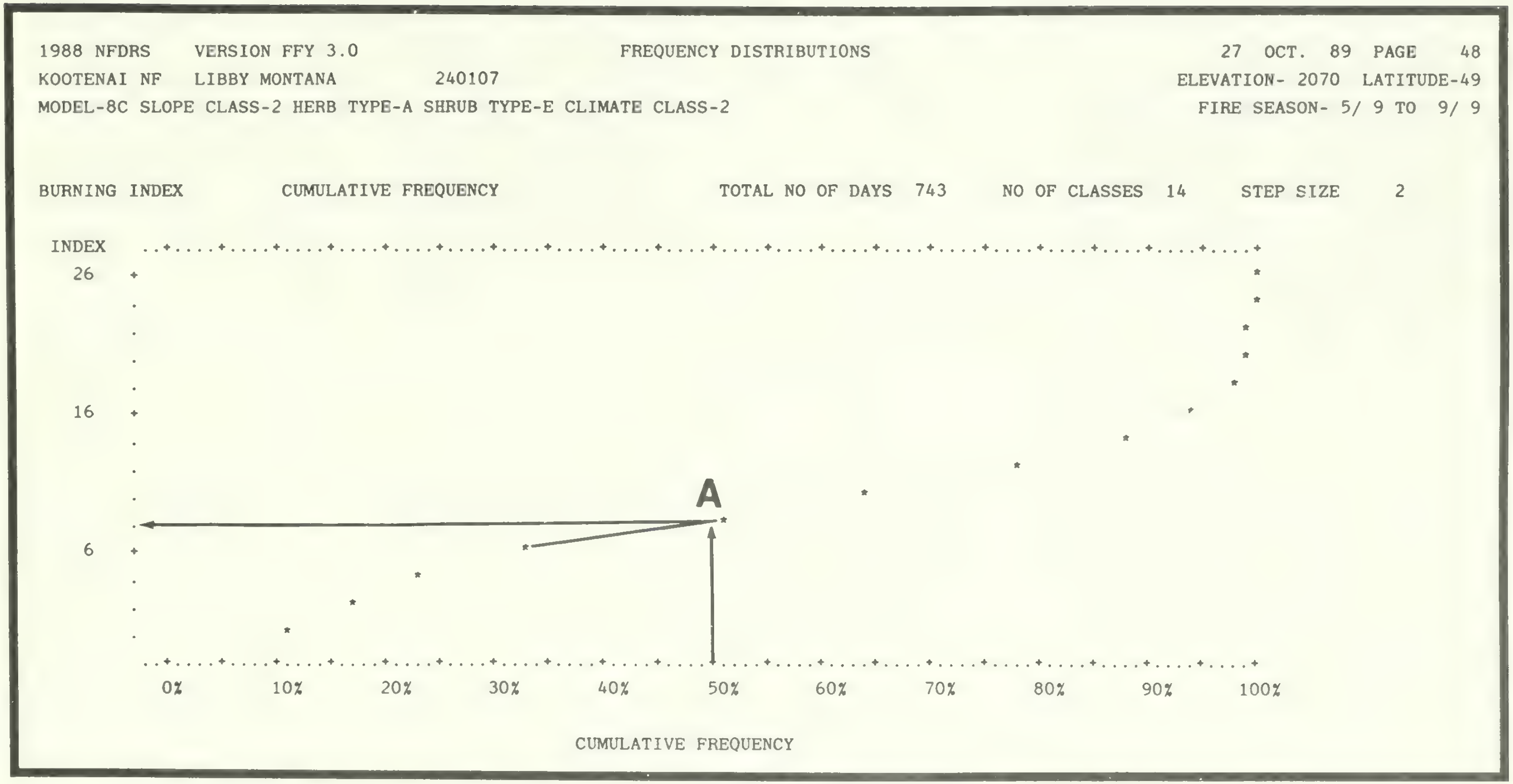


Figure 5.–*Frequency distributions graph.*

```
1988 NFDRS    VERSION FFY 3.0                          OBSERVED WEATHER ELEMENTS
KOOTENAI NF   LIBBY MONTANA          240107
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2
```

| DATE | S W | D B TMP | MOIS TURE | WIND SP | WIND DR | TEMP MAX | TEMP MIN | RH MAX | RH MIN | PRECIP AMNT | PRECIP DUR | LAL | HUM RSK | WOOD | HERB FM | 10HR | SEA SON | HRB GRN | WDY GRN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 750501 | 1 | 064 | 026 RH | 004 | S | 064 | 025 | 099 | 006 | 0000 | 00 | 001 | 010 | B | 42 | 011 | | | |
| 750502 | 3 | 062 | 039 RH | 001 | SE | 065 | 025 | 099 | 014 | 0000 | 00 | 001 | 010 | B | 42 | 010 | | | |
| 750503 | 3 | 061 | 034 RH | 001 | SE | 064 | 028 | 099 | 010 | 0011 | 08 | 001 | 010 | B | 42 | 025 | | | |
| 750504 | 2 | 050 | 069 RH | 001 | SE | 050 | 044 | 099 | 032 | 0000 | 00 | 001 | 010 | B | 42 | 025 | | | |
| 750505 | 3 | 051 | 070 RH | 001 | SE | 066 | 031 | 099 | 020 | 0011 | 08 | 001 | 010 | B | 42 | 025 | | | |
| 750506 | 5 | 056 | 067 RH | 002 | SE | 056 | 039 | 099 | 044 | 0005 | 12 | 001 | 010 | B | 42 | 024 | | | |
| 750507 | 2 | 063 | 057 RH | 002 | NE | 063 | 041 | 099 | 032 | 0004 | 08 | 001 | 010 | B | 42 | 025 | | | |

Figure 6.–*Observed weather elements.*

Next, you must specify a model-slope-herb-shrub-climate class combination. The model designation now requires two characters. The first character should be a 7 or an 8 to select a model from the 1978 or the 1988 fuel model set. The second character is the fuel model letter. Ordinarily this will be the same combination you use for your daily weather observations. Coding a T in column 53 will always set the 1-hour fuel moisture equal to the 10-hour fuel moisture. If you code an F in column 53, the 1-hour and 10-hour fuel moistures will be equal only on the day of and the day after rain. You should use all of the weather data available to you at the National Fire Weather Data Library. If you code 00 for the beginning of the range of years and 99 for the ending year in item 9, you will obtain output for all of your station's historic weather data.

FIRDAT allows you to specify the beginning and ending months and days of your fire season in item 10. Your fire season may begin in the fall and end in the spring or vice-versa. Note: You may skip over periods of low fire danger by specifying them on lead card two, item 9.

At this point, your selections on lead card one become even more important. For example, if you choose all the available variables, you will generate excess paper. If you choose only the variable or variables your agency uses for planning, your FIREFAMILY run will be quicker. You may choose up to nine variables in item 11 (columns 66-74): ignition component, spread component, energy release, human-caused fire occurrence, lightning-caused fire occurrence, burning index, fire load index, Keetch-Byram Drought Index, and/or fuel moistures. Code a "T" (true) in the appropriate column for each variable you want to see. Place an "F" (false) in the columns of the variables you don't want. If you code a "T" for dead fuel moistures, you will get all four: 1-hour, 10-hour, 100-hour, and 1,000-hour.

Next, you should decide if you wish to see the **daily list** of weather, components, and indexes. Place a "T" in column 75 to see the **daily list**. If you have already seen the **daily list**, placing an "F" in column 75 will save you money. Coding an "A" (for all combinations) will be expensive because it will cause the routine to print **daily lists** for all of the model-slope-herb-shrub-climate combinations that you select on lead card two.

The most important dollar-saving feature of FIREFAMILY is its ability to skip over FIRDAT when you have saved your **passing file** from a previous FIRDAT run. Code "T" in column 76 to skip FIRDAT and go directly to SEASON and/or FIRINF. Placing an "F" in column 76 will cause normal FIRDAT operation.

Placing a "T" in column 77 activates the weather-only feature (**observed weather elements**—fig. 6) of FIREFAMILY. Always place an "F" in column 77 unless you want only the raw weather data.

Placing a "T" in column 78 will cause the program to create a **passing file** (the file that passes information to SEASON and FIRINF). Because it is expensive to create the information on the **passing file**, you should save this file for later use with FIRINF and/or SEASON.

### FIRDAT Lead Card Two

Lead card two (Appendix Ib) gives you other FIRDAT options. You can provide information about risk assessments, dates for green-up and curing, average annual precipitation, beginning Keetch-Byram Drought Index and 1,000-hour fuel moisture, up to four additional combinations of model-slope-herb-shrub-climate, and you may specify a split fire season. If you are going to run SEASON and FIRINF together with FIRDAT, you may also redefine the upper boundaries of your manning percentiles on lead card two.

If you don't know your lightning risk scaling factor (LRS), use the value 01.00 in columns 2-6 of lead card two. If you run FIRDAT again, you should consult Deeming *et al.* (1977, Appendix D) to review guidelines for computing the lightning risk scaling factor. (See fig. 3, **B**, to find the total of lightning occurrence indexes in our example.)

You must provide estimates on lead card two for weekday and weekend human risk. The weekday (W) and weekend (E) values may range from 0 to 100 and should be recorded in columns 7-9 and 10-12.

If all your weather data include season and herb/woody greenness factors, you do not need to code columns 13-20 and you may skip to the next paragraph. However, if some of your weather data do not include season and herb/woody greenness factors, you must select the month and day when herbaceous plants usually start to green-up at your station. Code the month in card columns 13-14 and the day in 15-16. (Key abbreviation for green-up on lead card two in fig. 1 is GU.) Continue by specifying the earliest month and day on which you expect fall curing to begin. Herbaceous plants will not necessarily die on this day; instead FIRDAT begins to look for weather conditions that indicate freezing. If, for instance, a hard frost occurs with a minimum temperature of 25° or less, the NFDRS will "cure" the herbaceous fuels immediately. If no hard frost occurs, FIRDAT automatically records curing and dormancy after the fifth day with a minimum temperature of less than 33°. If minimum temperatures were not observed for your station, the date you specified in columns 17-20 will be used as the curing date. If your area never experiences freezing, enter 1232 in columns 17-20.

The average annual precipitation, entered in columns 21-24, is used to calculate the Keetch-Byram Drought Index. Enter the value for rain plus the water equivalent of snowfall.

Enter zero in columns 25-27 for the beginning Keetch-Byram Drought Index if weather observations normally begin when the soil is still fully moist. Burgan (1988) provides a table to estimate a beginning Keetch-Byram Drought Index if weather observations normally begin after significant soil drying has occurred.

The default 1,000-hour fuel moisture depends on the climate class assigned to the station—15, 20, 25, or 30 for climate classes 1, 2, 3, or 4, respectively. You must enter one of these default values in columns 28-29, or you can enter an estimate of your own. For example, if weather data collection normally begins after significant drying has occurred, you may wish to enter a value lower than the default value.

Because of diverse fuel types and topography, you might want to process your data with more than one combination of model-slope-herbaceous class-shrub type-climate. If so, indicate as many as four additional combinations in card columns 30-53. For example, if you have two different forest types near your weather station, you could process the data for upland hardwood stands (NFDRS Model 8E) and, with the same set of lead cards, process the conifer types (NFDRS Model 8H). If, on lead card two, you change your climate class, shrub type, or herbaceous code, you may have to use a new lead card one to redefine the green-up and curing dates.

Many areas of the country have a two-part fire season. The Southeast, for example, has a fall season of October and November and a spring season of February to April. With that pattern, running cumulative frequencies for dates from October to April will include the 2 months of low fire occurrence (December and January), thereby biasing the results. To avoid this bias, skip the low risk period by coding its beginning month in columns 54-55, the beginning day in columns 56-57, the ending month in columns 58-59, and the ending day in columns 60-61. If you do not have a split fire season, leave these columns blank.

The first time you use FIREFAMILY, you should run FIRDAT by itself, saving the **passing file**. You can then analyze the FIRDAT cumulative frequency tables to find the index values necessary to calculate your manning classes. If you want to include SEASON and/or FIRINF in the first run, FIRDAT provides an option that calculates a set of ranges for one index. Choose the number of the variable (1-8) from the list in item 10 and code it in card column 62 (see Appendix Ib). This code will cause FIRDAT to calculate the ranges that will become the rows and/or columns for

your SEASON and FIRINF tables. **However, we strongly recommend that you do not attempt to run SEASON or FIRINF in the first run with FIRDAT.**

The USDA Forest Service uses the 90th and 97th percentiles to delineate the high and very high manning classes. If your agency uses other values, you should enter them in columns 63-64 and 65-66 on lead card two.

## SEASON ROUTINE

The severity of fire weather varies during the year. The SEASON routine summarizes these variations and reveals seasonal patterns over many years to help fire managers plan. SEASON will tabulate and/or graph the values of any of the fuel moistures, indexes, or components the fire manager wishes to analyze.

SEASON has three major sections: **seasonal tables** and **graphs**, monthly **persistence probability tables**, and the cumulative **BI seasonal severity list** and **summary table**. The **seasonal tables** show the average, highest, and lowest values of the chosen variable for each day of the year. **Seasonal graphs** map the general character of the fire season shown in the **seasonal tables**. The **persistence probability tables** report the chance that tomorrow's variable will be the same as today's. The **BI seasonal severity summary table** ranks the fire seasons of each year according to their difficulty, based on the 90th percentile of the burning index. Remember that BI severity measures only the effect of weather, not fire activity.

### Seasonal Table

The **seasonal table** shows—for each variable you select—the mean, maximum, and minimum values for the averaging period as well as the number of weather observations recorded over the period of years indicated at the top of the table (fig. 7). All the observed data are included in the **seasonal table**, not just the data from the fire season. To save money and paper, choose only the variable(s) most important for planning.

In figure 7, we chose the BI **(A)**. We also selected an averaging period of 5 days **(B)**. This running mean is an average calculated from an odd number of consecutive days, centered on the observation date. The longer the period chosen for the running mean, the smaller the day-to-day changes in the average will be. This "smoothing" of the daily averages will make a graph of this information easier to interpret. Smoothing periods of 3 to 7 days are usual.

### Graphing Options

SEASON provides the option for graphing the tabulated information in figure 7. If you ask for such a graph (Appendix Ic, card column 11 = T), you will get one page of printout for every 2 months shown in the table. You will also receive a graph legend that explains symbols used, years included, and the scale the computer selected to lay out the graph.

SEASON can also graph the data 1 day at a time, year after year. This feature might give you insight into a particularly bad year or show how drought affects out-of-season wildfires. **Be careful, however, because this feature can generate massive volumes of paper**. To save paper and money, select the variable or variables of greatest concern (columns 3-10, Appendix Ic), use the combination of model-slope-herb-shrub-climate on lead card one only, and turn off the SEASON tables (column 12 = F). To activate this **single year graph** feature, code column 15, lead card 3, with a "T."

### Fire Manager's Graph

You can easily construct a graph of your own data. Figure 8 is a graph of the seasonal variations of the BI. You can use graph paper that includes a year-by-day legend along the bottom. To find the range of the variable that we were plotting, we consulted our **frequency distributions table** (fig. 4). Because the upper boundary of the 97th percentile was 17.46, we used 0-17 as the range for our vertical scale. We used the upper boundaries of the 90th and 97th percentiles as well as the information contained in table 1 to draw five horizontal manning class lines. Bold **A** (fig. 8) shows that we drew the line for the upper boundary of our 90th percentile at a BI of 15 (14.56, rounded up).

Next, we transferred the daily mean values from the **seasonal table** to the graph and connected them with a solid line. The dashed lines indicate that less than 5 years of data was available. (We used a running mean of 5 days to smooth our curve.) This curve shows the seasonal variation in the burning index. Finally, we drew vertical lines at the beginning **(B)** and end **(C)** of our fire season.

You could also plot your daily maximum and minimum values from the **seasonal table**. Once you have used your historical weather data to create your seasonal graph, you can use this graph to compare your current daily values with the averages. Lay a clear plastic sheet over your seasonal graph and plot current observed values on it.

1988 NFDRS VERSION FFY 3.0 SEASONAL TABLE 27 OCT. 89 PAGE 110
KOOTENAI NF LIBBY MONTANA 240107 ELEVATION- 2070 LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2 FIRE SEASON- 5/ 9 TO 9/ 9

BURNING INDEX **A** 220 DAY PERIOD FOR 6 YEARS STARTING DATE JULY 2 5 DAY RUNNING MEAN **B**

YEARS OF DATA 1972, 73, 74, 75, 76, 77.

| DATE | RUNNING 5-DAY MEAN | MAX VALUE | MIN VALUE | NUMBER OF DAYS |
|---|---|---|---|---|
| JULY 2 | 8.90 | 17 | 5 | 30 |
| JULY 3 | 8.57 | 16 | 6 | 30 |
| JULY 4 | 8.50 | 16 | 5 | 30 |
| JULY 5 | 8.43 | 11 | 0 | 30 |
| JULY 6 | 8.10 | 17 | 5 | 30 |
| JULY 7 | 7.77 | 14 | 2 | 30 |
| JULY 8 | 8.07 | 18 | 0 | 30 |
| JULY 9 | 7.83 | 12 | 0 | 30 |
| JULY10 | 7.63 | 15 | 5 | 30 |

| DATE | RUNNING 5-DAY MEAN | MAX VALUE | MIN VALUE | NUMBER OF DAYS |
|---|---|---|---|---|
| AUG 16 | 7.87 | 20 | 0 | 30 |
| AUG 17 | 8.40 | 16 | 0 | 30 |
| AUG 18 | 9.10 | 18 | 0 | 30 |
| AUG 19 | 9.47 | 13 | 1 | 30 |
| AUG 20 | 9.83 | 18 | 7 | 30 |
| AUG 21 | 9.40 | 15 | 8 | 30 |
| AUG 22 | 8.87 | 16 | 7 | 30 |
| AUG 23 | 7.97 | 17 | 0 | 30 |
| AUG 24 | 7.53 | 12 | 0 | 30 |

Figure 7.–*Seasonal table.*

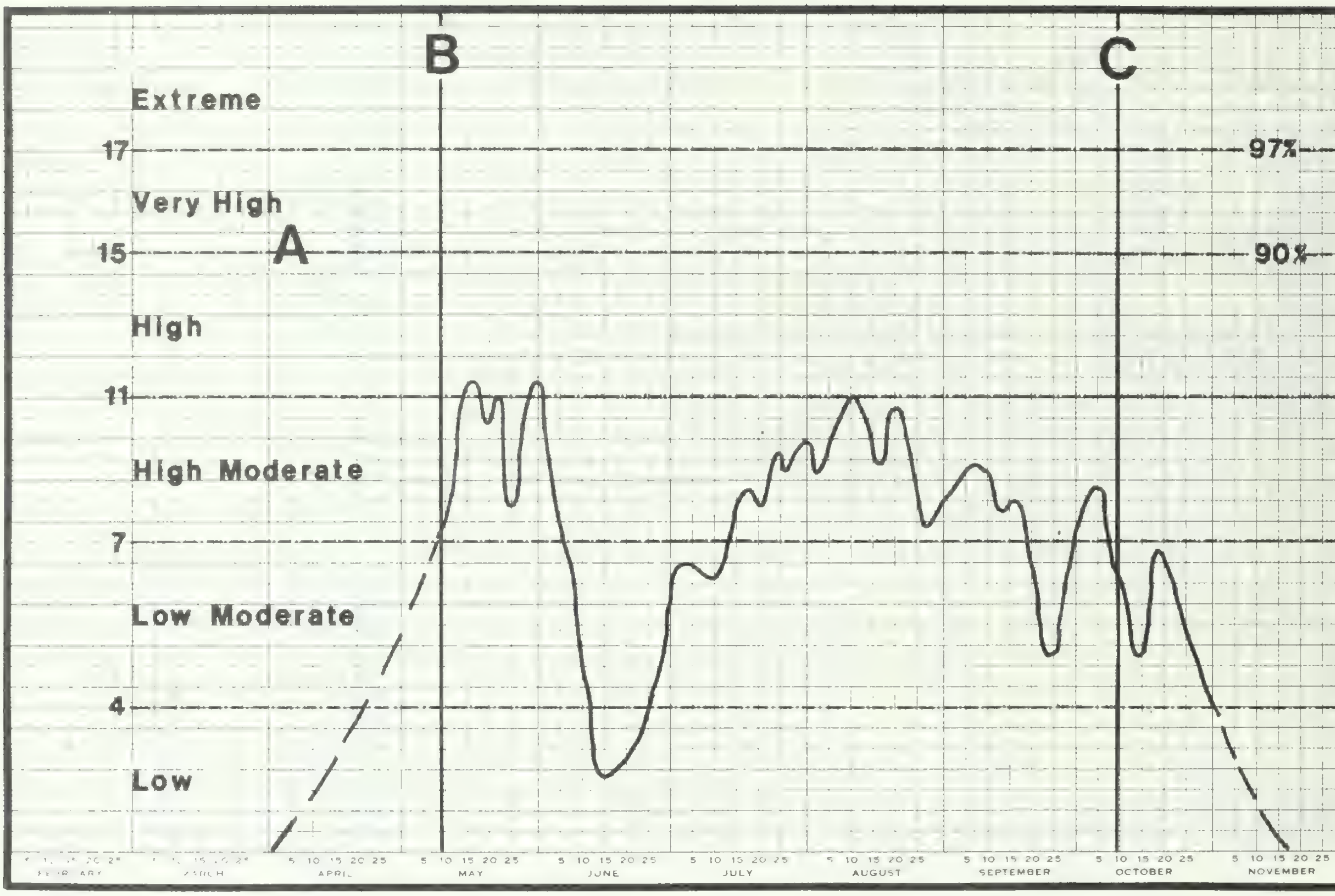


Figure 8.–*Fire manager's hand-drawn seasonal graph of the BI.*

If you asked for the computer printed graphs of the **seasonal tables**, you could draw the manning classes and the seasonal curve on them, but it would be difficult to overlay a plastic sheet on such a large graph.

### Persistence Probability Table

Persistence measures how likely something is to remain the same. The fraction of the time that the weather will be the same tomorrow as it is today is tabulated in the SEASON's **persistence probability table** (fig. 9). The higher the persistence, the less likely the weather will change. SEASON produces monthly **persistence probability tables** for the chosen variable.

Information at the top of the table indicates the total number of years, the month for which data are being tabulated, and the specific years included. One page of output will be produced for each month of data. In our example, the burning index is divided into six manning classes (using table 1). These six classes make up both the row and column headings in each of the three parts of figure 9. Today's BI's are found in the rows **(A)** and tomorrow's BI's are found in the columns **(B)**. The ranges illustrated in the **persistence probability table** were computed by FIRDAT. However, you can select them by coding on lead card three (see Appendix Ic, item 9).

The **persistence probability table** reports the total number of pairs of days that were found **(C)**. (A pair occurs whenever there are weather observations on 2 consecutive days.) Out of a possible 186 pairs (31 days x 6 years), 180 pairs were found. The greatest number of pairs occurred when the BI was in the 5-8 class 1 day and continued in the same class through the next day 29 times **(D)**.

Figure 9 is divided into three parts. The top third tells how many times each pair of BI's (today's and tomorrow's) falls within each of the manning class ranges (both rows and columns). In our example, **E** shows that the BI was in the extreme range 2 days in a row (both today and tomorrow) two times in the 6 years under study.

1988 NFDRS VERSION FFY 3.0 PERSISTENCE PROBABILITY
KOOTENAI NF LIBBY MONTANA 240107
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2

--PERSISTENCE-- 6 YEARS OF DATA FOR AUG

YEARS OF DATA 1972, 73, 74, 75, 76, 77,

TOMORROWS BURNING INDEX (AUG ) 180 PAIRS **C**

| TODAYS BURNING **B** | 0- 4 | 5- 8 | 9- 11 | 12- 15 | 16- 17 | 18- 26 |
|---|---|---|---|---|---|---|
| **A** 0 - 4 | 18 | 13 | 2 | 0 | 0 | 0 |
| 5 - 8 | 8 | 29 **D** | 8 | 0 | 0 | 0 |
| 9 - 11 | 7 | 1 | 17 | 17 | 0 | 0 |
| 12 - 15 | 2 | 2 | 12 | 18 | 6 | 4 |
| 16 - 17 | 0 | 0 | 2 | 4 | 2 | 1 |
| 18 - 26 | 0 | 0 | 0 | 4 | 1 | 2 **E** |
| 0 - 4 | 54.55 | 39.39 | 6.06 | .00 | .00 | .00 |
| 5 - 8 | 17.78 | 64.44 | 17.78 | .00 | .00 | .00 |
| 9 - 11 | 16.67 | 2.38 | 40.48 | 40.48 | .00 | .00 |
| 12 - 15 | 4.55 | 4.55 | 27.27 | 40.91 | 13.64 | 9.09 |
| 16 - 17 | .00 | .00 | 22.22 | 44.44 | 22.22 | 11.11 |
| 18 - 26 | .00 | .00 | .00 | 57.14 **F** | 14.29 | 28.57 |
| 0 - 4 | 10.00 | 7.22 | 1.11 | .00 | .00 | .00 |
| 5 - 8 | 4.44 | 16.11 | 4.44 | .00 | .00 | .00 |
| 9 - 11 | 3.89 | .56 | 9.44 | 9.44 | .00 | .00 |
| 12 - 15 | 1.11 | 1.11 | 6.67 | 10.00 | 3.33 | 2.22 |
| 16 - 17 | .00 | .00 | 1.11 | 2.22 | 1.11 | .56 |
| 18 - 26 | .00 | .00 | .00 | 2.22 | .56 | 1.11 **G** |

Figure 9.–*Persistence probability table.*

The middle third tells what percentage of the time a BI today was followed by each of the BI ranges tomorrow. The bottom row of the middle section **(F)** shows that if our BI is 18-26 today, then 57 percent (57.14) of the time tomorrow's BI will be in the 12-15 range. The chance that today will be followed by the next range (16-17) is 14 percent. Finally, the chance that the BI tomorrow will be in the same range as it is today is 29 percent. The fire manager could use this section of the table to predict the range of tomorrow's burning index after observing today's BI. The fire manager would want to pay particular attention to very high or extreme conditions. As the previous example showed, if the BI is in the extreme range today, there is a 29 percent chance that tomorrow's BI will also be in the extreme range. These historic data are used primarily to determine if firefighters should be ready to attack tomorrow's fires.

The bottom third of the figure indicates the percentage of the time that any particular combination of today's and tomorrow's values occurs. For example, the

occurrence of extreme days following one another **(G)** is only 1.11 percent of the time in August. This means that the fire organization should plan to have 2 of their worst days back-to-back about once every third August (1.11 percent of 31 days in August = 0.34 days or about once every third August).

Note: If you want to see your persistence probability, **don't** turn on the **single year graph** feature in SEASON.

### BI Seasonal Severity

The seasonal severity routine uses the burning index to rank how severe the fire weather was each year. Seasonal severity 1) lists those days that have a BI exceeding the 90th percentile and 2) summarizes the data by months and year.

### BI Seasonal Severity List

The **BI seasonal severity list** (fig. 10) ranks each year at a fire weather station in terms of the burning index. The ranking takes into account both how often and by how much each day's BI exceeded the 90th percentile BI level. The column headings **(A)** identify the dates that exceeded the 90th percentile BI, the BI value on these dates, the cumulative departures, and finally, the number of days in that year that the BI exceeded the 90th percentile. The program shows the upper boundary of the 90th percentile BI (90% = 15) **(B)**.

We see that the first day in 1972 to exceed the 90th percentile value was May 19. The difference (17-15 = 2) was entered in the cumulative departure column. The cumulative departure totals the daily departures (Daily departures = $BI_{today} - BI_{90\ percentile}$). The August 11 daily departure (16-15 = 1) was added to the previous two cumulative departure points to equal three cumulative departure points and so on.

Our example also shows the beginning of the 1973 fire season **(C)** where we note 8 days in a row exceeding the 90th percentile BI (from May 15 to May 22). Such periods would force a fire suppression group to respond day after day at its maximum strength.

```
1988 NFDRS    VERSION FFY 3.0                         BI SEASONAL SEVERITY LIST
KOOTENAI NF   LIBBY MONTANA           240107
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2


CUMULATIVE BI SEVERITY

A  DATE       BI      CUMULATIVE      NUMBER        B 90%=  15 (VALUE MAY BE CALCULATED OR SET.)
             VALUE    DEPARTURE       OF DAYS
   72 519     17          2              1
   72 811     16          3              2
   72 829     18          6              3
   72 830     19         10              4
   7210 3     16         11              5
   7210 5     16         12              6
   7210 7     16         13              7



   73 515  C  17          2              1
   73 516     25         12              2
   73 517     19         16              3
   73 518     19         20              4
   73 519     26         31              5
   73 520     17         33              6
   73 521     18         36              7
   73 522     16         37              8
   73 531     18         40              9
   73 6 1     16         41             10
   73 6 4     17         43             11
```

Figure 10.–*BI seasonal severity list.*

**BI Seasonal Severity Summary Table**

The data in the **BI seasonal severity list** are summarized in the **BI seasonal severity summary table** (fig. 11). The months **(A)** are listed horizontally above the summarized information. The cumulative departures and the number of days above the 90th percentile value for all the months are tabulated **(B)**. Both the total departures (113) and the number of days above the 90th percentile (38) are shown at **C**. The annual ratings for 1973 **(D)** show that the total departures were 3.340 times greater than the average. Similarly, the day count **(E)** shows that there were 2.923 more days above the 90th percentile than normally occur. The product of the BI and day columns **(F)** for 1973 is 9.763. The average annual departure and number of days are reported at **G**. Our example shows that in these 6 years, the average BI departure was 33.8 and the average number of days above the 90th percentile was 13.00. Because the station has a 123-day fire season, we expected about 11 percent of the days to exceed the 90th percentile level.

Remember that this method evaluates the weather of each year, not wildfire activity.

**SEASON Lead Card Three**

Appendix Ic describes the coding necessary for the SEASON routine. Code 3 in card column 1 (item 1) identifies a SEASON lead card. SEASON can plot the NFDRS components and indexes (item 3, list 1), the weather elements (item 3, list 2), or the living and dead fuel moistures (item 3, list 3). You choose the list you want by coding the number 1, 2, or 3 in card column 2. Then from that list select the variables that you want tabulated or graphed. You **must** select one list and at least one variable or SEASON will not function. Leave the card column blank for every variable you don't want tabulated or graphed.

You may select **seasonal graphs**, **tables**, or both by coding a "T" or "F" in columns 11 and 12 (items 4 and 5). The averaging period for graphs and tables (columns 13-14) must be an odd number between 01 and 31 (item 6). If you choose 1 day, a jagged graph will result. Increasing the averaging period will "smooth" the graph (see fig. 8 for an example). Use 3, 5, or 7 days as your running mean for a "smoothed" graph.

If you want a graph of individual years, code "T" in column 15 (item 7). Because this feature has limited value, you will usually code "F." Note: The **single year graph** feature automatically turns off the **BI seasonal severity list** and **summary table** and **persistence probability tables**. It may also create excessive paper and expense (see Appendix II, item 7).

If you don't want any **persistence probability tables**, enter a 0 in column 16, item 8. However, if you do want a **persistence probability table**, you must choose one of the NFDRS indexes or components from item 3 that you coded in columns 3-10. Code the number of the variable in column 16. (For example, in fig. 9 we coded list number 1 in card column 2 and coded 6 in column 8, so we could again code 6—the burning index—in card column 16.)

You will usually run FIRDAT first, analyze the data, and then run SEASON. (SEASON will use weather data from the **passing file**.) As part of this analysis, you will find the 90th and 97th percentile values of your variable on your **frequency distributions table** (fig. 4, **I**). Item 9 tells you to code your upper boundary levels in columns 17-34 on lead card three. In our example (table 1), we would code 004 in columns 17-19, 007 in columns 20-22, and so on.

You can force FIRDAT to compute the upper boundaries of the variable chosen in item 8 by running FIRDAT and SEASON at the same time and placing the number of the variable from the list in item 3 into column 62 on lead card two. The computer will then automatically calculate the upper and lower boundaries and you need not fill in columns 17-34 in item 9 on lead card three.

You may obtain the **BI seasonal severity list** and **summary table** by placing a "T" in column 35 (item 10). If this SEASON run immediately follows a FIRDAT run, SEASON will remember the 90th percentile value of the BI, so leave item 11 blank. However, if you run SEASON independently with the **passing file**, then you must specify the 90th percentile BI in columns 36-38.

The **BI seasonal severity summary table** (fig. 11) can be produced in two ways. If this is a run with FIRDAT, you should leave columns 39-48 blank. The routine will calculate the average departure points and number of days and print them (fig. 11, **G**). Later, you may wish to compare the BI seasonal severity with different average values for the departures and number of days. You can instruct the routine to use these values by placing them in card columns 39-48. In our example, the columns on lead card three were left blank and the computer determined the average values.

1988 NFDRS VERSION FFY 3.0 BI SEASONAL SEVERITY SUMMARY 27 OCT. 89 PAGE 63
KOOTENAI NF LIBBY MONTANA 240107 ELEVATION- 2070 LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2 FIRE SEASON- 5/ 9 TO 9/ 9

THESE SEVERITY RATINGS ARE BASED ON AVERAGE DATA, NOT USER SUPPLIED. BI(90%)= 15

| | A | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | JAN | FEB | MARCH | APRIL | MAY | JUNE | JULY | AUG | SEPT | OCT | NOV | DEC | TOTALS | RATINGS | | |
| | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | DEP-DY | BI | DAY | BI X DAY |
| 1972 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 2- 1 | 2- 1 | 2- 1 | 10- 4 | 10- 4 | 13- 7 | 13- 7 | 13- 7 | 13- 7 | .384 | .538 | .207 |
| | | | | | | | | B | | | | | C | D | E | F |
| 1973 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 40- 9 | 43-11 | 82-25 | 112-37 | 113-38 | 113-38 | 113-38 | 113-38 | 113- 38 | 3.340 | 2.923 | 9.763 |
| 1974 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 12- 5 | 12- 5 | 12- 5 | 13- 6 | 22- 7 | 22- 7 | 22- 7 | 22- 7 | 22- 7 | .650 | .538 | .350 |
| 1975 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | .000 | .000 | .000 |
| 1976 | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 9- 6 | 9- 6 | 11- 7 | 11- 7 | 11- 7 | 11- 7 | 11- 7 | 11- 7 | 11- 7 | .325 | .538 | .175 |
| 1977 | 0- 0 | 0- 0 | 0- 0 | 4- 3 | 5- 4 | 20- 9 | 44-19 | 44-19 | 44-19 | 44-19 | 44-19 | 44-19 | 44- 19 | 1.300 | 1.462 | 1.901 |
| TOTAL | | | | | | | | | | | | | 203- 78 | | | |
| AVRGE | 0- 0 | 0- 0 | 0- 0 | 0- 0 | 10- 3 | 3- 1 | 10- 4 | 6- 2 | 1- 0 | 0- 0 | 0- 0 | 0- 0 | 33.8- 13.00 | | | |
| YEARS= 6 | | | | | | | | | | | | | G | | | |

Figure 11.–*BI seasonal severity summary table.*

## FIRINF ROUTINE

Although SEASON analyzes only one NFDRS variable at a time, FIRINF can provide information on combinations of two variables. Many agencies combine two variables to determine their adjective or manning classes. For example, fire managers often combine the IC (a measure of fire occurrence) with the BI (a measure of fire intensity) to determine these classes. They can use these FIRINF tables for planning detection flights, wildfire prevention activities, industrial closures, and specific action guides. Both SEASON and FIRINF get their data from the **passing file** produced by FIRDAT. The FIRINF routine uses only the first 3,600 days of historical weather data, so you may wish to decide which 10 years are the most important to you and code them on a new lead card one (see Appendix Ia, item 9).

### Adjective Class Matrix

The **adjective class matrix** (fig. 12) is one of the most frequently used fire management tools. It combines the IC with the agency's manning class index or component to help provide the public with fire-danger levels.

Figure 12 demonstrates how the BI was used to provide the manning classes. The values FIRE-FAMILY computed for you or that you entered on lead card four (Appendix Id) are displayed at **A** in figure 12. Bold letter **B** shows the first pair of "x values" (0-20), which defines the boundaries of the first column. Each subsequent pair defines another column. The **adjective class matrix** always includes the same five ranges of the ignition component. The first "y value" pair (0-4) defines the first row of the BI. The other pairs define the remaining rows.

In figure 12, the row with a BI of 12-13 shows two "M's" (moderate), two "H's" (high), and a "V" (very high) in the columns from left to right. Other symbols found in the matrix are "L" (low) and "E" (extreme). A summary of the number of days in the data base and the number of days actually used is shown at the bottom of the printout.

This table provides the fire manager with a quick overview of how the IC and BI together affect the adjective class levels. For clarity we have outlined the area of the table containing the very high and extreme days **(C)**.

Instead of the **adjective class matrix**, you can obtain the **precautions class matrix**, a similar table often used to determine forest closures. The **precautions class matrix** uses a different range of column headings for the IC and allows the user to choose the variable (often the energy release component or the BI) to determine the manning classes.

FIRINF also provides you with an opportunity to form your own matrix to give you more information than that offered in either the **adjective** or **precautions class matrices**. You may combine any two of the eight variables listed on lead card four to produce the user-defined matrix. You may have to use a second or third lead card four for this purpose. Place "F's" in columns 2 and 3. Code the first variable number in column 4 and the second in column 35 and specify up to 10 upper boundaries of each index or component in the provided card columns (see Appendix Id).

### Adjective Class Calendar

The **adjective class calendar** (fig. 13) indicates the adjective levels assigned by the **adjective class matrix** to each day for which you have historical weather data. **Precautions class** or **user-defined matrices** also produce a similar calendar.

FIRINF prints out the date (year—72, month—08, day—09) **(A)**. A dot (.) is printed above the first digit of the year. (Notice that the dates are printed below one another in groups of seven, indenting one column each time.) The adjective class letter (M—moderate) for the first date is printed in the row labeled M. (A row is provided for each class—L, M, H, V, E.) You can easily see the changes in adjective levels on a daily basis.

Find August 30, 1972, in the calendar **(B)**. Using a straight edge, draw a line up from the 7 (the first digit of the year) beyond its dot through the letter H **(C)**. Use this method to find the adjective rating for any day in your data base. In general, you will look at your calendar for repeated very high (V) or extreme (E) days. The **adjective class calendar** graphically illustrates persistence of adjective levels. In the **precautions class** and **user-defined matrices**, the letters A, B, C, D, E, and F are used to show class categories. "A" is the lowest level of fire danger.

### Probability Analysis

Once you have asked for the **adjective class matrix**, you will get an **adjective class calendar** as well as monthly and annual **probability analysis tables**. These **probability analysis tables** will provide you with some of the detailed information necessary to

plan your fire management activities. The tables will show how often you can expect values of your adjective class to occur. In figure 14, the table rows indicate the ranges of numerical values for the BI and the columns indicate the ranges of the ignition component.

The **probability analysis table** is divided into three parts. The top third **(A)** tells how often combinations of the BI and the IC occurred. Our example shows that in the 1,111 days for which we have data, there were 11 days when the BI was 18-21 and the IC was in the range of 0-20. On 8 other days, when the BI was 18-21 the IC was in the range of 21-45.

The middle of the table **(B)** tells the percent of the time that the ignition component is in each column, given that the BI is in a particular row. For example, in the BI row labeled 22-26 we see that 25 percent of the time the ignition component was in the range 0-20 and 75 percent of the time the ignition component was in the 21-45 range.

```
1988 NFDRS    VERSION FFY 3.0                         SUMMARY OF FIRINF VARIABLES
KOOTENAI NF   LIBBY MONTANA           240107
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2

                                      A
                X VALUES              Y VALUES
                0        20           0       4
               21        45           5       8
               46        65           9       9
               66        80          10      11
               81       100          12      13
              101         0          14      15
                0         0          16      16
                0         0          17      17
                0         0          18      21
                0         0          22      26

                                  THE ADJECTIVE   CLASS MATRIX

        ***********************************************************************************
        * BURNING  *                        IGNITION COMPONENT                            *
        *  INDEX   ************************************************************************
        *         B 0- 20* 21- 45* 46- 65* 66- 80* 81-100*101-  0*  0-  0*  0-  0*  0-  0*  0-  0*
        ***********************************************************************************

        *   0-  4  *  L   *  L   *  L   *  M   *  M   *      *      *      *      *      *
        *   5-  8  *  L   *  M   *  M   *  M   *  H   *      *      *      *      *      *
        *   9-  9  *  M   *  M   *  H   *  H   *  V   *      *      *      *      *      *
        *  10- 11  *  M   *  M   *  H   *  H   *  V   *      *      *      *      *      *
        *  12- 13  *  M   *  M   *  H   *  H   *  V   *   C  *      *      *      *      *
        *  14- 15  *  M   *  M   *  H   *  H   *  V   *      *      *      *      *      *
        *  16- 16  *  M   *  H   *  V   *  V   *  E   *      *      *      *      *      *
        *  17- 17  *  M   *  H   *  V   *  V   *  E   *      *      *      *      *      *
        *  18- 21  *  H   *  V   *  V   *  E   *  E   *      *      *      *      *      *
        *  22- 26  *  H   *  V   *  V   *  E   *  E   *      *      *      *      *      *
        ***********************************************************************************

   1111 DAYS OF RECORD ACCEPTED FROM  1111 DAYS READ FROM THE PASSING FILE.
```

Figure 12.–*Adjective class matrix.*

```
1988 NFDRS    VERSION FFY 3.0                              CLASS CALENDAR                     27  OCT.  89  PAGE   129
KOOTENAI NF   LIBBY MONTANA          240107                                              ELEVATION- 2070  LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2                           FIRE SEASON- 5/ 9 TO  9/ 9


          IGNITION COMPONENT           JOINED WITH  BURNING  INDEX




E
V                    V
H  H                 H C
M MM MMMMMMMMMM MMMMMM  MMMMMM MMMMM MMM MMMM     M MMMMMMMMMMM    MMMM   MM  M
L          L              L      L   L   LLLLLL L           LLLL    LLL  LL LLLLLL
  . . . . . . . . . . . . B . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
A 720809 720816 720823 720830 720906 720913 720920 720927 721004 721011 721018 721025
   720810 720817 720824 720831 720907 720914 720921 720928 721005 721012 721019 721026
    720811 720818 720825 720901 720908 720915 720922 720929 721006 721013 721020 721027
     720812 720819 720826 720902 720909 720916 720923 720930 721007 721014 721021 721028
      720813 720820 720827 720903 720910 720917 720924 721001 721008 721015 721022 721029
       720814 720821 720828 720904 720911 720918 720925 721002 721009 721016 721023 721030
        720815 720822 720829 720905 720912 720919 720926 721003 721010 721017 721024 721031
```

Figure 13.–*Adjective class calendar.*

```
1988 NFDRS    VERSION FFY 3.0                        PROBABILITY ANALYSIS                     27  OCT.  89  PAGE   136
KOOTENAI NF   LIBBY MONTANA        240107                                                 ELEVATION- 2070  LATITUDE-49
MODEL-8C SLOPE CLASS-2 HERB TYPE-A SHRUB TYPE-E CLIMATE CLASS-2                             FIRE SEASON- 5/ 9 TO  9/ 9
```

IGNITION COMPONENT VERSUS BURNING INDEX

| | BURNING INDEX | IGNITION COMPONENT 0- 20 | 21- 45 | 46- 65 | 66- 80 | 81-100 | 101- 0 | 0- 0 (1111 DAYS IN TOT.) | 0- 0 | 0- 0 | 0- 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0- 4 | 290 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 5- 8 | 294 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 9- 9 | 89 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10- 11 | 152 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12- 13 | 133 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 14- 15 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 16- 16 | 33 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 17- 17 | 13 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 18- 21 | 11 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 22- 26 | 2 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | 0- 4 | 100.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 5- 8 | 100.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 9- 9 | 100.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 10- 11 | 100.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 12- 13 | 100.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 14- 15 | 100.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 16- 16 | 97.06 | 2.94 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 17- 17 | 76.47 | 23.53 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 18- 21 | 57.89 | 42.11 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 22- 26 | 25.00 | 75.00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| C | 0- 4 | 26.10 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 5- 8 | 26.46 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 9- 9 | 8.01 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 10- 11 | 13.68 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 12- 13 | 11.97 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 14- 15 | 6.75 | .00 | .00 | .00 | .00 | D .00 | .00 | .00 | .00 | .00 |
| | 16- 16 | 2.97 | .09 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 17- 17 | 1.17 | .36 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 18- 21 | .99 | .72 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| | 22- 26 | .18 | .54 | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |

Figure 14.–*Probability analysis table.*

The lower third of the table **(C)** tells the percentage of all the days on which each combination of the BI and IC occurred. Thus in our example, on 0.99 percent of the 1,111 days, the BI was in the range of 18-21 and the ignition component had a value between 0-20. Similarly, on 0.72 percent of the days, the BI was between 18 and 21, and the ignition component ranged from 21 to 45.

**Probability analysis tables** are helpful to fire managers using historical weather data for planning and budgeting. On figure 12 we outlined the area of the table containing the very high and extreme days. We have used the same rows and columns to outline the identical portion of figure 14 **(D)**. Adding all of the percentages within the outlined area, we find that a total of 1.26 percent of the 1,111 days were in the very high or extreme range in the past. Therefore, the fire manager would budget for an average of 5 very high and/or extreme days per year.

In addition to the monthly **probability analysis tables**, you will receive a yearly **probability analysis table** showing the same kind of information.

If you ask for a **precautions class** or **user-defined matrix**, you will receive **probability analysis tables** for them also. You can analyze them in the same way that you analyzed the **probability analysis table** for adjective classes.

### FIRINF Lead Card Four

An example of the FIRINF lead card is shown at the bottom of the FIREFAMILY header page (fig. 1, **D**). A "4" printed in card column 1 (Appendix Id, item 1) identifies each FIRINF card. Item 2, Appendix Id, allows the user to select or reject the **adjective class matrix** by coding a "T" (true) or an "F" (false) in card column 2. If you run FIRDAT and FIRINF at the same time and you code a "6" in card column 62 of lead card two, FIRDAT will then compute the upper boundaries of your BI. Because the computer will then automatically provide the ranges of the BI, you need not fill in the rest of lead card four. When requesting the **adjective class matrix**, you must code an "F" in column 3 of lead card four. You can leave card column 4 blank because the IC is always used in the **adjective class matrix**. Both columns 2 and 3 may be coded false.

Usually you will be running FIRINF with a previously created **passing file**. The program will compute the upper boundaries of the IC for you, so leave columns 5-34 blank. But you must code the number of the variable you want combined with the IC into card column 35. Use our table 1 or Appendix E of the AFFIRMS manual (Helfman *et al.* 1987) to find a method to determine up to 10 upper boundaries of your chosen variable. Enter these boundaries in card columns 36-65.

A similar table to the **adjective class matrix**—the **precautions class matrix**—can be selected by coding an "F" in card column 2 and a "T" in card column 3. Just as for the **adjective class matrix**, if you are running FIRINF with FIRDAT and code number 3 (ERC) in card column 62 of lead card two, FIRDAT will provide the row ranges, so you can leave the rest of lead card four blank. If you have run FIRDAT previously, however, follow the coding routine suggested for the **adjective class matrix**, but use the ERC, the BI, or another variable for the rows.

Instead of selecting either the **adjective** or **precautions class matrices**, you can construct any other table by combining two variables from the list in Appendix Id, item 4. You might wish to construct your own table because your agency does not use the same method for determining manning classes that has been provided by FIRINF, or you may wish to choose indexes or components other than those provided by FIRINF. Code as follows: put the code number of your chosen column variable in card column 4 and the row variable in column 35. Constructing tables this way requires you to enter up to 10 of the upper boundaries for the ranges of the chosen variables. These numbers will appear in the columns and rows on the table you are constructing. Enter upper boundaries for the first variable in card columns 5-34, leaving any unused columns blank. Choose up to 10 upper boundaries for the second variable and code these numbers in columns 36-65 (item 7).

## CONCLUSION

We have shown how your historical weather data can be combined with the NFDRS to produce a variety of useful planning tools. The **frequency distributions tables** indicate the highest fire-danger levels of each index or component. The SEASON printouts show when to expect periods of sustained high fire danger. Indexes and components are combined in the **adjective** and **precautions class matrices** to provide both the public and private sectors with estimates of potential fire danger.

Now that you have seen what FIREFAMILY can do for you, your next step is to determine what your needs are and submit the appropriate lead cards to your

computer specialist. (You can photocopy the lead cards in Appendix I to make coding simpler.) The specialist will then combine your lead cards with the Fort Collins job-control cards shown in Appendix III.


### ACKNOWLEDGMENTS

FIREFAMILY began as a collection of separate programs written by several people. The authors gratefully acknowledge the work of David Rainey, Robert J. Straub, and the late R. William Furman for their early contributions to FIREFAMILY. We also thank Roger L. Bradshaw for his patience and help in refining the program. Finally, we thank Mike Burbank for his assistance with the camera-ready figures.


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## APPENDIX I.–LEAD CARD FORMATS

Two kinds of computer instructions are required to operate FIREFAMILY—program lead cards and job-control cards. Program lead cards are discussed thoroughly in this publication. Below we summarize general information about the program lead cards and suggest general rules for submitting the cards to the computer. Appendix II illustrates the number of pages likely to be produced. Appendix III shows the job-control cards needed to execute FIREFAMILY at Fort Collins and the format of the **passing file**. We have included this information in the Appendices for easy reference by your computer specialist.

There are four types of program lead cards: lead cards one and two control FIRDAT, lead card three controls SEASON, and four controls FIRINF. The identification number, always coded in column 1 of each card, determines how the program interprets the contents of that card. The cards must be properly formatted and submitted to the computer in the correct order. General rules are:

1. The lead cards must be entered from low card number to high for the same weather station.

2. More than one station may be included in the same run. (Submit a card one for each station.)

3. Order the lead card "ones" from lowest station number to highest.

4. Lead cards three and four do not have to be present in a run.

5. The first card in an entire group must be a card one.

6. The second card in an entire group must be a card two.

7. Once a card two, three, or four is entered, its instructions will remain in effect until altered by another card of the same type.

8. Cards three and four can exist in multiples of three cards each for the same station.

## Ia.–FIRDAT Control–Lead Card One

| ITEM | DESCRIPTION | CARD COLUMN(S) |
|---|---|---|
| 1 | Card Number | (1) _1_ |
| 2 | Administrative owner's name | (2-13) ________________ |
| 3 | Station name | (14-33) ____________________ |
| 4 | Station number | (34-39) __ __ __ __ __ __ |
| 5 | Station elevation in feet (right justify) | (40-44) __ __ __ __ __ |
| 6 | Station latitude, nearest degree | (45-46) __ __ |
| 7 | NFDRS model-slope-herb-shrub-climate class combination (lead card two permits four additional combinations): | |
| | Model: 7 or 8 and A through U but not M | (47-48) __ __ |
| | Slope: 1 through 5 | (49) ___ |
| | Herbaceous: A or P only, annual or perennial | (50) ___ |
| | Shrub: D or E only, deciduous or evergreen | (51) ___ |
| | Climate Class: 1 through 4 | (52) ___ |
| 8 | 1 hr = 10 hr: Code true (T) or false (F) only. | (53) ___ |
| 9 | Range of years: First year | (54-55) __ __ |
| | Last year | (56-57) __ __ |
| | (Enter 00 and 99 to get all available data.) | |
| 10 | Fire season: Beginning month | (58-59) __ __ |
| | Beginning day | (60-61) __ __ |
| | Ending month | (62-63) __ __ |
| | Ending day | (64-65) __ __ |
| | (Enter 01 01 and 12 31 to include the entire year. Item 9 on lead card two allows you to skip a period of few fires.) | |
| 11 | If you want **frequency distributions tables** and **graphs** for particular indexes, components, and fuel moistures, code "T." Code "F" for those you don't want. | |
| | Variable: | |
| | Ignition component (IC) | (66) ___ |
| | Spread component (SC) | (67) ___ |
| | Energy release component (ERC) | (68) ___ |
| | Human-caused fire occurrence index (HCOI) | (69) ___ |
| | Lightning-caused fire occurrence index (LOI) | (70) ___ |
| | Burning index (BI) | (71) ___ |
| | Fire load index (FLI) | (72) ___ |
| | Keetch-Byram Drought Index (KDI) | (73) ___ |
| | Fuel moistures (FM) (You will get all four: the 1-hr, 10-hr, 100-hr, and 1,000-hr.) | (74) ___ |
| 12 | "T" produces a **daily list** of the weather, indexes, and components. This item is reset to "F" after the first model-slope-herb-shrub-climate combination has been processed. If you choose more than one combination on lead card two (item 7), and you want the **daily list** for each combination, code "A" (for ALL). An "F" will suppress all **daily lists**. | (75) ___ |
| 13 | "T" indicates you have a FIRDAT-created **passing file**; you will go directly to SEASON and/or FIRINF. | (76) ___ |
| 14 | "T" will list only the observed weather elements; no indexes or components will be printed. | (77) ___ |
| 15 | "T" causes FIRDAT to create a **passing file** for use with SEASON and/or FIRINF. | (78) ___ |

## Ib.–FIRDAT Control–Lead Card Two

| ITEM | DESCRIPTION | CARD COLUMN(S) |
|---|---|---|
| 1 | Card number | (1) _2_ |
| 2 | Lightning risk scaling (LRS) factor. For the first run, enter 01.00. On later runs, adjust your LRS as indicated in Deeming *et al.*, Appendix D (1977). | (2-6) __ __ __ __ __ |
| 3 | Human-caused risk scaling factors. Columns 7-9 contain the average weekday risk and columns 10-12 contain the average weekend risk | (7-9) __ __ __<br>(10-12) __ __ __ |
| 4a | Month and day when green-up begins | (13-16) __ __ __ __ |
| 4b | Month and day of the first killing frost | (17-20) __ __ __ __ |
| 5 | Average annual precipitation (in inches) | (21-24) __ __ __ __ |
| 6 | Beginning Keetch-Byram Drought Index | (25-27) __ __ __ |
| 7 | Beginning 1,000 hour timelag fuel moisture. Enter a station specific value if available. Otherwise, enter one of the following values (to the nearest whole percent), depending on which climate class you designated on lead card 1, column 52: (see table below) | (28-29) __ __ |
| 8 | Up to four more model-slope-herb-shrub-climate combinations may be entered (see Appendix Ia, item 7). | (30-35) __ __ __ __ __ __<br>(36-41) __ __ __ __ __ __<br>(42-47) __ __ __ __ __ __<br>(48-53) __ __ __ __ __ __ |
| 9 | If your station has a split fire season, you may enter the low risk period here:<br>Beginning month and day<br>Ending month and day | <br>(54-57) __ __ __ __<br>(58-61) __ __ __ __ |
| 10 | You may select one variable from the following list and use its code number to have SEASON and FIRINF construct a variety of tables. (Leave blank if you are not using SEASON and/or FIRINF on this run.) (see table below) | (62) __ |
| 11 | If you leave columns 63-66 blank, this program will print the 90th and 97th percentile levels of the index or component chosen in card column 62. Because your agency's planning methods may vary from those used by the USDA Forest Service, you may choose, for example, the 80th and 95th percentile levels. If so, code 8095. | (63-66) __ __ __ __ |

Item 7:

| Climate Class | Beginning 1,000 Hour |
|---|---|
| 1 | 15 |
| 2 | 20 |
| 3 | 25 |
| 4 | 30 |

Item 10:

| Code | Variable |
|---|---|
| 1 | IC |
| 2 | SC |
| 3 | ERC |
| 4 | HCOI |
| 5 | LOI |
| 6 | BI |
| 7 | FLI |
| 8 | KDI |

# Ic.–SEASON Control–Lead Card Three

| ITEM | DESCRIPTION | CARD COLUMN(S) |
|---|---|---|
| 1 | Card number | (1) _3_ |
| 2 | SEASON will graph and/or tabulate variables from one of these lists: 1 = NFDRS, 2 = Weather Elements, 3 = Fuel Moistures. Code your choice of list here. | (2) ___ |
| 3 | From the item 2 list, select and code the number of any or all of the variables. Leave the column blank if you don't want to see a variable tabulated or graphed. | |

| Code | List 1 **NFDRS** | List 2 **Weather Elements** | List 3 **FM** | Card column |
|---|---|---|---|---|
| 1 | IC | Temp | 1-hr | (3) ___ |
| 2 | SC | RH | 10-hr | (4) ___ |
| 3 | ERC | Wind | 100-hr | (5) ___ |
| 4 | HCOI | Prec. dur. | 1,000-hr | (6) ___ |
| 5 | LOI | Prec. amt. | Woody | (7) ___ |
| 6 | BI | LAL | Herb | (8) ___ |
| 7 | FLI | Herb greenness factor | | (9) ___ |
| 8 | KDI | Woody greenness factor | | (10) ___ |

| ITEM | DESCRIPTION | CARD COLUMN(S) |
|---|---|---|
| 4 | **Seasonal graphs**? "T" = yes, "F" = no. | (11) ___ |
| 5 | **Seasonal tables**? "T" = yes, "F" = no. | (12) ___ |
| 6 | Averaging periods for tables and graphs; code with an odd number, 01-31 only. | (13-14) __ __ |
| 7 | Graph individual years? "T" = yes, "F" = no. This feature may produce many pages of printout. It also turns off the **persistence probability tables** and the **BI seasonal severity list** and **summary table**. | (15) ___ |
| 8 | Persistence probability variable: use one variable code from the list you chose in item 3. Code 0 if you do not want a **persistence probability table**. | (16) ___ |
| 9 | Select up to six upper boundaries for your persistence probability variable. (FIRDAT will do this if you place a code in column 62 of lead card two.) Enter boundaries in ascending order, right justified. | (17-19) __ __ __<br>(20-22) __ __ __<br>(23-25) __ __ __<br>(26-28) __ __ __<br>(29-31) __ __ __<br>(32-34) __ __ __ |
| 10 | **BI seasonal severity list** and **summary table**? "T" = yes, "F" = no. | (35) ___ |
| 11 | Enter the 90th percentile BI value. Leave blank if you are combining SEASON with a FIRDAT run (round off BI value, no decimal point, right justify). | (36-38) __ __ __ |
| 12 | To compare BI seasonal severity with different averages for the departures and number of days, enter average yearly departure, with decimal point, in columns 39-43, and enter the average yearly number of days over the percentile in columns 44-48. (Leave columns 39-48 blank unless you want this feature.) | (39-43) __ __ __ __ __<br>(44-48) __ __ __ __ __ |

Note: You may have up to three SEASON cards in each run. To turn SEASON off, leave the card blank except for the code "3" in column 1.

## Id.–FIRINF Control–Lead Card Four

| ITEM | DESCRIPTION | CARD COLUMN(S) |
|---|---|---|
| 1 | Card number | (1) _4_ |
| 2 | **Adjective class matrix**? "T" = yes, "F" = no. If "T" is coded in column 2, "F" must be coded in column 3. (Both columns 2 and 3 may be false.) | (2) ___ |
| 3 | **Precautions class matrix**? (See above.) | (3) ___ |
| 4 | Choose the variable to be used for the table columns from the following list: | |
| | Code — Variable | |
| | 1 — IC | |
| | 2 — SC | |
| | 3 — ERC | |
| | 4 — HCOI | |
| | 5 — LOI | |
| | 6 — BI | |
| | 7 — FLI | |
| | 8 — KDI | (4) ___ |
| 5 | Code up to 10 upper boundary values for the table columns. | (5-7) ___ ___ ___ |
| | | (8-10) ___ ___ ___ |
| | | (11-13) ___ ___ ___ |
| | | (14-16) ___ ___ ___ |
| | | (17-19) ___ ___ ___ |
| | | (20-22) ___ ___ ___ |
| | | (23-25) ___ ___ ___ |
| | | (26-28) ___ ___ ___ |
| | | (29-31) ___ ___ ___ |
| | | (32-34) ___ ___ ___ |
| 6 | Choose a code number for another variable from the list in item 4 for the table rows. | (35) ___ |
| 7 | Code up to 10 upper boundary values for the rows. | (36-38) ___ ___ ___ |
| | | (39-41) ___ ___ ___ |
| | | (42-44) ___ ___ ___ |
| | | (45-47) ___ ___ ___ |
| | | (48-50) ___ ___ ___ |
| | | (51-53) ___ ___ ___ |
| | | (54-56) ___ ___ ___ |
| | | (57-59) ___ ___ ___ |
| | | (60-62) ___ ___ ___ |
| | | (63-65) ___ ___ ___ |

Note: This card may be repeated up to three times. Turn FIRINF off by coding card columns 2 and 3 false and leaving the rest of the card blank.

## APPENDIX II.–OUTPUT PAGE ESTIMATOR

| FEATURES | PAGES | TOTAL PAGES* |
|---|---|---|
| ) **Header page** | 1 page per combination | 5 |
| ) **Daily list** (if T) | Total days/50 | 60 |
| (if A) | Total days x combinations/50 | 300 |
| ) **Annual summary** | Years x combinations | 100 |
| ) **Cumulative frequency** | 2 pages x combinations x frequencies selected | 110 |
| ) **SEASON graph** | 4 pages x combinations x variables selected x SEASON cards | 420 |
| ) **SEASON tables** | 3 pages x combinations x variables selected x SEASON cards | 315 |
| ) **Single year graph** | Multiply item 5 or item 6 x years | 8,400(5) |
| | | 6,300(6) |
| ) **Persistence probability** | 6 pages x combinations x SEASON cards | 90 |
| ) **BI seasonal severity** | 5 pages x combinations | 45 |
| ) **FIRINF** | 22 pages x combinations x FIRINF cards | 330 |

With five combinations, 20 years (3,000 days), and everything turned on (three SEASON and three FIRINF rds), the output would be 15,545 pages.

te: When the **single year graph** feature is on, FIREFAMILY produces a great deal of paper even though it ns off everything else in SEASON.

## APPENDIX III.–JOB RUNSTREAMS AND PASSING FILE FORMAT

e Fort Collins Computer Center, home of FIRE-MILY, is equipped with a UNIVAC 1100 series com-er and the EXEC 9 operating system. Changes in CC equipment or systems may make the following amples and job instructions obsolete.

e first part of Appendix III will help your computer ecialist set up the job-control language needed to ecute FIREFAMILY at FCCC.

We have included two typical runstreams. The first shows how to access the National Fire Weather Data Library (see Furman and Brink 1975) to obtain historical weather records, execute the FIREFAMILY program, and catalog the **passing file**. Our second example shows how to use a previously created **passing file** as input to the FIREFAMILY routines SEASON and FIRINF.

Appendix IIIc shows the format of the **passing file**.

## IIIa.–Running FIREFAMILY Using Historical Weather Data

```
@Run,P/B YOUR ID,ACCOUNT NUMBER,QUALIFIER,TIME,PAGES
@ASG,A FIREDATALIB★PROGRAMS.
@ASG,A FIREDATALIB★21-24. (Get the fire weather tape.)
@ASG,UP YOUR-DATA. (Unconditionally catalog the weather holding file.)
@USE 2.,FIREDATALIB★21-24.
@USE 15., YOUR-DATA.
@XQT FIREDATALIB★PROGRAMS.GETDATA2 (Get the required weather data.)
24010700 24010799
@EOF
@ASG,UP PASS. (Unconditionally catalog the passing file.)
@USE 7.,YOUR-DATA. (Use the data just obtained from the NFWDL.)
@USE 9.,PASS.
@HDG,N X.M,66,0,0 (Turn off normal page control.)
@XQT NFDR88★FIREFAMILY.FIRDAT1 (Execute the program.)
1KOOTENAI NF LIBBY MONTANA          240107 2070498C2AE2F009905090909TTTTTTTTTTFFT
2 1.00 12 120601091020.300020                  69097
3112345678TT01F6
4TF
@SAVE QUALIFIER ★PASS.,900301 (Save the passing file until March 1, 1990.)
MY FIRDAT PASSING FILE'S NAME
        (The qualifier must be explicitly specified and the above file description line must be included.)
@FIN
```

## IIIb.–Running FIREFAMILY Using a Previously Created Passing File

```
@RUN,P/B YOUR ID,ACCOUNT NUMBER,QUALIFIER,TIME,PAGES
@ASG,A QUALIFIER ★PASS. (Assign previously created passing file to this run.)
@USE 9.,QUALIFIER ★PASS.
@HDG,N X.M,66,0,0 (Turn off normal page control.)
@XQT NFDR88★FIREFAMILY.FIRDAT1 (Execute the program.)
1KOOTENAI NF LIBBY MONTANA          240107 2070498C2AE2F0099050909FFFFFFFFFFTFF
2 1.00 12 120501091020.300020                  69097
3112345678TT01F3
4FT
@FIN
```

(*Parenthetical expressions explain each job-control card.*)
*UPPER CASE ITALICS* indicate where coding will differ from run to run.

# IIIc.–FIREFAMILY Passing File Format

e **passing file**, a product of FIRDAT, is used to nsfer weather, fuel moistures, and NFDRS compo- nts and indexes from FIRDAT to SEASON and/or RINF. If retained after the FIRDAT run, this com- ter readable file can be reused as input to SEASON d/or FIRINF. It may also be used as input to future alysis programs.

e **passing file** contains three kinds of records: a g indicating a change of station or change of station rameters, a header reporting the station parameters, d the daily data values.

| Item | Columns | Type* |
|---|---|---|
| ECORD ONE, Flag: | | |
| lag: 999999999999 | 1-12 | N |
| ECORD TWO, Header: | | |
| dministrative owner | 1-12 | A-N |
| ation name | 13-32 | A-N |
| ation number | 33-38 | N |
| evation | 39-43 | N |
| titude | 44-45 | N |
| iel model | 46 | A |
| ope class | 47 | N |
| erbaceous type | 48 | A |
| imate class | 49 | N |
| lian green-up date | 50-52 | N |
| in date | 53-64 | A-N |
| lian first freeze | 65-67 | N |
| eginning and ending years | 68-71 | N |
| RECORD THREE, Daily Data: | | |
| Station number | 1-6 | N |
| Date | 7-12 | N (year-month-day) |
| Julian date | 13-15 | N |
| Processing option | 16 | N |
| State of weather | 17 | N |
| Temperature | 18-20 | N |
| Relative humidity | 21-23 | N |
| Wind direction | 24 | N (8 point compass |
| Wind speed | 25-27 | N |
| Max temperature | 28-30 | N |
| Min temperature | 31-33 | N |
| Max relative humidity | 34-36 | N |
| Min relative humidity | 37-39 | N |
| Precipitation duration | 40-41 | N (hours) |
| Precipitation amount | 42-45 | N (10.94 written as 1094) |
| Lightning activity level | 46 | N |
| Human-caused risk | 47-49 | N |
| 1-hour fuel moisture | 50-52 | N (14.5 written as 145) |
| 10-hour fuel moisture | 53-55 | N (14.5 written as 145) |
| 100-hour fuel moisture | 56-58 | N (14.5 written as 145) |
| 1,000-hour fuel moisture | 59-61 | N (14.5 written as 145) |
| Woody moisture | 62-64 | N |
| Herbaceous moisture | 65-67 | N |
| Blank | 68-69 | N |
| Ignition component | 70-72 | N |
| Spread component | 73-75 | N |
| Energy release component | 76-78 | N |
| Human-caused fire occurrence index | 79-81 | N |
| Lightning-caused fire occurrence index | 82-84 | N |
| Burning index | 85-87 | N |
| Fire load index | 88-90 | N |
| Keetch-Byram index | 91-93 | N |
| Herb greenness factor | 94-96 | N |
| Woody greenness factor | 97-99 | N |

*A-N = Alpha-numeric data fields contain alphabetic (A) l/or numeric (N) characters.*

# APPENDIX IV.–ANALYZING NFDRS WEATHER DATA USING 1978 OR 1988 FUEL MODELS

The FIRDAT routine of FIREFAMILY was revised after the NFDRS fuel models were revised in 1988. Fire managers can now use FIREFAMILY 1988 to analyze historical weather data collected both before and after 1988. The following describes how FIRDAT addresses the four combinations of 1978 and 1988 fuel model sets and styles of weather data.

**Running a 1988 fuel model set with the 1978 style of weather data:**

1. Allows the fire manager the option to set the fine fuel moisture always equal to the 10-hour fuel moisture. Even if the fire manager does not select this option, FIRDAT will make the fine fuel moisture equal to the 10-hour fuel moisture on the day of and the day after more than 0.1 inch of precipitation.
2. Adjusts the 1988 wind reduction factor between minimum and maximum values by comparing today's live woody vegetation load to the maximum live woody vegetation load for the model. The wind reduction factor will vary only for the deciduous models. It is not possible to adjust the wind reduction factor as a function of the woody greenness factor because the latter did not exist in the 1978 style of weather data.
3. Multiplies the wind reduction factor by 0.3 on the day of and the day after at least 0.1 inch of precipitation.
4. Does not alter the calculation procedures of the 100-hour, 1,000-hour, live woody, and live herbaceous moistures. They are the same as when running a 1978 fuel model set with 1978 style weather data.
5. Modifies the fine fuel load through curing of grasses and loss of leaves from deciduous live woody vegetation.
6. Modifies the 1-hour, 10-hour, 100-hour, and 1,000-hour fuel loads as a function of the Keetch-Byram Drought Index to account for the addition of fuel due to deep drying of litter and duff.
7. Does not change the procedure for adjusting the live herbaceous load. It is the same as when using a 1978 fuel model set with 1978 style weather.
8. Increases the deciduous live woody load in the spring and decreases it in the fall (after a freeze) over a period equal to the climate class times 7 days.

**Running a 1988 fuel model set with the 1988 style of weather data:**

1. Allows the fire manager the option to set the fine fuel moisture equal to the 10-hour fuel moisture. Even if the fire manager does not select this option, FIRDAT will make the fine fuel moisture equal to the 10-hour fuel moisture on the day of and the day after more than 0.1 inch of precipitation.
2. Adjusts the 1988 wind reduction factor between minimum and maximum values as a function of the woody greenness factor. The wind reduction factor will vary only for the deciduous models.
3. Multiplies the wind reduction factor by 0.3 on the day of and the day after at least 0.1 inch of precipitation.
4. Does not alter the calculation procedures of the 100-hour, 1,000-hour, live woody, and live herbaceous moistures. They are the same as when running a 1978 fuel model set with 1978 style weather data.
5. Modifies the fine fuel load through curing of grasses and loss of leaves from deciduous, live woody vegetation.
6. Modifies the 1-hour, 10-hour, 100-hour, and 1,000-hour fuel loads as a function of the Keetch-Byram Drought Index to account for the addition of fuel due to deep drying of litter and duff.
7. Modifies the live woody and live herbaceous fuel moistures by their respective greenness factors.
8. Modifies the deciduous woody load and live herbaceous load by their respective greenness factors.
9. For the deciduous models, modifies the midflame windspeed as a function of the live woody greenness factor.

**Running a 1978 fuel model set with the 1978 style of weather data (FIRDAT acts as though the 1988 NFDRS revisions never occurred):**

1. Never makes the 1-hour fuel moisture equal to the 10-hour fuel moisture, even on the day of and the day after rain.

)oes not adjust the wind reduction factor assigned o the 1978 fuel model.

Calculates all live and dead fuel moistures with the 1978 method.

Adjusts the fine fuel load by the addition of cured grass only.

Keeps the 10-hour, 100-hour, and 1,000-hour loads constant.

Modifies the live herbaceous load by the greening and curing of grasses and herbs; the fall curing process is instantaneous.

Keeps the live woody load constant.

**nning a 1978 fuel model set with the 1988 style weather data:**

Never makes the 1-hour fuel moisture equal to the 10-hour fuel moisture even on the day of and the day after rain.

Does not adjust the wind reduction factor assigned o the 1978 fuel model.

Does not change the 100-hour and 1,000-hour fuel moisture calculations from those in the 1978 NFDRS.

Does not adjust either the live herbaceous or woody fuel moisture for the effect of drought.

Cures the live herbaceous and woody fuels instantly, not gradually.

Does not adjust the windspeed for the greenness factor or after precipitation.

Adjusts the fine fuel load for the curing of herbaceous fuels only.

Does not adjust the 10-hour, 100-hour, and 1,000-hour fuels for drought.

Does not adjust the live herbaceous and woody loads as a function of greenness factors.

# APPENDIX V.– ABBREVIATIONS AND GLOSSARY

## Abbreviations

| | |
|---|---|
| **BI** | –Burning index |
| **ERC** | –Energy release component |
| **FLI** | –Fire load index |
| **FM** | –Fuel moisture |
| **HCOI** | –Human-caused fire occurrence index |
| **HCR** | –Human-caused risk |
| **HCRSF** | –Human-caused risk scaling factor |
| **IC** | –Ignition component |
| **KDI** | –Keetch-Byram Drought Index |
| **LAL** | –Lightning activity level |
| **LOI** | –Lightning fire occurrence index |
| **LR** | –Lightning risk |
| **LRS** | –Lightning risk scaling factor |
| **NFDRS** | –National Fire-Danger Rating System |
| **SC** | –Spread component |
| **TL** | –Timelag |
| **1-hr TL FM** | –1-hour timelag fuel moisture content |
| **10-hr TL FM** | –10-hour timelag fuel moisture content |
| **100-hr TL FM** | –100-hour timelag fuel moisture content |
| **1,000-hr TL FM** | –1,000-hour timelag fuel moisture content |

## Glossary

**Adjective class matrix**.–The table that combines the manning classes (usually based on the BI) with the IC to specify the standard levels of fire danger for public information.

**Burning index (BI)**.–An NFDRS value related to the contribution of fire behavior to the effort of containing a fire. The BI measures fire intensity (BI = 10 x flame length).

**Components of the NFDRS**.–Components include ignition, spread, and energy release.

**Cumulative departure**.–The sum of the daily departures (usually for a year).

**Cumulative frequency.**–The sum of all of the frequencies up to and including this one.

**Daily departure**.–The numerical difference between the daily value of the variable and the 90th percentile value of that variable when the daily value is greater than the 90th percentile value.

**Energy release component (ERC)**.–A number related to the available energy (Btu) per unit area (square foot) within the flaming front at the head of a fire.

**FIRDAT**.–A routine of FIREFAMILY that combines historical weather records with the equations of the NFDRS to produce frequency distributions of the NFDRS indexes and components.

**Fire-danger rating area**.–A geographical area within which the fire danger can be assumed to be uniform. It is relatively homogeneous in climate, fuels, and topography.

**FIREFAMILY**.–A computer program that uses historical weather data for fire planning. Its three major routines are FIRDAT, SEASON, and FIRINF.

**Fire load index (FLI)**.–A rating of the maximum effort required to contain all probable fires occurring within a rating area during the rating period.

**Fire season**.–A period during which weather and fuels are conducive to wildfires. (Also, see split fire season.)

**FIRINF**.–A routine of FIREFAMILY that uses data from FIRDAT to create tables of combinations of two NFDRS indexes and components.

**Frequency (also relative frequency)**.–Proportion of occurrences of a value at a particular numerical level compared with all occurrences.

**Fuel model**.–A simulated fuel complex for which all the fuel descriptors required by the mathematical fire spread model have been specified.

**Fuel moisture content (also fuel moisture) (FM)**.–The water content of a fuel particle expressed as a percent of the ovendry weight of the fuel particle. The six NFDRS fuel moistures are woody, herbaceous, 1-hour, 10-hour, 100-hour, and 1,000-hour.

**Header page**.–The first page of output, which repeats the user-supplied lead card information.

**Herb**.–A plant that does not develop woody, persistent tissue but is relatively soft or succulent and sprouts from the base (perennials) or develops from seed (annuals) each year. Included are grasses, forbs, and ferns.

**Herbaceous fuels**.–Undecomposed material, living or dead, derived from herbaceous plants.

**Herbaceous greenness factor**.–A number from 0 through 20 that indicates the relative level of herbaceous greenness. Zero indicates fully cured, while 20 indicates the grass is as green as it ever gets. The fire weather observer enters intermediate values during the spring greening process, the fall curing, or during drought periods when plants are under significant moisture stress.

**Human-caused fire occurrence index (HCOI)**.–A rating value formed by combining HCR with today's IC. It is related to the expected number of reported wildfires in the rating area.

**Human-caused risk (HCR)**.–A number related to the expected number of human-produced firebrands capable of starting fires that a rating area will be exposed to during the rating period.

**Human-caused risk scaling factor (HCRSF)**.–A number relating human-caused fire incidence to the IC on a rating area. The factor is a statistic based on 3 to 5 years of fire occurrence and fire weather data that adjusts the prediction of the basic human-caused fire occurrence model to fit local experience.

**Ignition component (IC)**.–The rating of the probability that a firebrand will cause a wildfire requiring suppression action.

**Indexes of the NFDRS**.–Human-caused fire occurrence, lightning-caused fire occurrence, burning, and fire load.

**Job runstream**.–See runstream.

**Keetch-Byram Drought Index (KDI)**.–A number that has a direct relationship to drought stress. It is expressed from 0 to 800 with 800 being the maximum stress.

**Lead card**.–The user-supplied part of the job runstream that provides information and chooses options for the FIREFAMILY program.

**Lightning activity level (LAL)**.–A numerical rating of 1 to 6, keyed to the start of thunderstorms and the frequency and character of cloud-to-ground lightning, forecast or observed on a rating area during the rating period.

**Lightning fire occurrence index (LOI)**.–A numerical rating of the potential occurrence of lightning-caused fires.

**Lightning risk (LR)**.–A number related to the expected number of cloud-to-ground lightning discharges capable of starting fires that a rating area will be exposed to during the rating period.

**Lightning risk scaling factor (LRS)**.–A factor derived from local thunderstorm and lightning-caused fire records that adjusts the predictions of the basic lightning fire occurrence model to local experience. It accounts for factors not addressed directly by the model such as susceptibility of local fuels to ignition by lightning, fuel continuity, topography, and regional characteristics of thunderstorms.

**Manning classes (also manning levels)**.–The minimum strength of forces which an agency plans to activate at each level of fire danger.

**Matrix**.–As used in this publication, another word for table.

**Passing file**.–A product of FIREFAMILY that saves FIRDAT data for later use with SEASON and/or FIRINF.

rsistence probability.–As used in this publication, the fraction of the time that the weather will remain the same 2 days in a row.

ecautions class matrix.–A table (used principally in the USDA Forest Service Region 6, the Pacific Northwest) that uses the ERC or the BI with the IC. One use of the precautions class matrix is to regulate industrial forest usage.

lative frequency.–See frequency.

nstream (also job runstream).–Series of control cards used at Fort Collins to run FIREFAMILY.

ason.—A routine of FIREFAMILY that uses FIRDAT's results to tabulate and graph one NFDRS index, component, or fuel moisture at a time to show seasonal weather patterns.

ason of the year.–An important entry for calculating live fuel moistures in the 1988 NFDRS. Coded numerically as 1–winter, 2–spring, 3–summer, and 4–fall.

**Split fire season**.–Two or more periods of many wildfires separated by a period of few fires.

**Spread component** (SC).–A rating of the forward rate of spread of a head fire expressed in feet per minute.

**Variable**.–As used in this publication, any of the NFDRS indexes or components. In FIRDAT and SEASON, fuel moistures are also considered variables.

**Woody greenness factor**.–A number from 0 through 20 that indicates the relative level of shrub greenness. Zero indicates that all the leaves have fallen off deciduous shrubs or that evergreen shrubs are dormant. Twenty indicates the shrub leaves are fully developed and not under moisture stress. The fire weather observer enters intermediate values during the spring greening process, the fall curing, or during drought periods when plants are under significant moisture stress.

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This revised user's guide will help fire managers interpret the output from FIREFAMILY, a computer program that uses historic weather data for fire planning. With the changes in the National Fire-Danger Rating System, all Forest Service units will need to rerun their historical weather data and use this publication to revise their fire plan. The guide describes options within the program and explains various tables and graphs necessary for planning. It also provides computer specialists with details needed to run the program.

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KEY WORDS: Fire weather, fire danger, National Fire-Danger Rating System, fire planning, historic weather data

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

NORTH CENTRAL FOREST EXPERIMENT STATION